

A COMPUTER APPROACH TO ESTIMATING
AND MAN POWER CONTROL IN MANUFACTURING

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ABSTRACT

In this dissertation, a new approach for computerized estimating for manufacturing and multiproject scheduling is presented. The dissertation is divided into two main parts. The first part is on the subject of estimating where a new approach for developing standard estimating data through mathematical modelling is described along with the method to code parts and operations in such a way as to minimize the number of time formulas and the computing time effort. As an application various steps for the development of a computer program for estimating labour time for manufacturing heat exchangers are presented.

The second part deals with the subject of multiproject scheduling and man-power control. Here the object of the approach is to propose a mathematical model for scheduling work progress for each individual project and the total man-hour level required for all projects. By comparing the actual job completion to scheduled or forecast completion the status of jobs is determined. Proper production monitoring and optimizing of the cost involved can be realized through continuous updatings of such production plans as the one presented in this investigation.

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CHAPTER I

INTRODUCTION

Historically, production management was performed purely on an empirical basis. Decisions were usually based on the result of trial and error, experimentation and experience. There was little tendency to investigate analytically various production problems. This is understandable because even the simplest production system involves many variables.

The new trend in production management is to develop techniques based on analytical approaches using the methods already available in other fields especially in engineering and mathematics.

With the availability of computers in many industrial organizations, it is now possible to handle problems involving a great many variables in modern production management. When the variables in any production system have been identified and their relationships defined, it is then possible to utilize computers for the solution of production engineering problems.

In this dissertation, two areas of production management are discussed, namely:

- (i) Estimating.
- (ii) Multiproject scheduling and control.

The function of estimating is to give cost data for bidding contracts, for evaluating alternative designs and investments, to allocate time for scheduling and manpower control.

Estimating has a very empirical basis even in large industrial organizations. An estimating standard manual usually consists of tables or charts showing the relationships between the variables. This method of estimating is time consuming and not reliable since it leaves much to individual judgment and furthermore such estimates cannot be verified.

A new analytical approach for estimating, adaptable to computerized solutions is presented in Chapter II. The main ideas of this chapter are :

- (i) survey of various actual methods for cost estimation
- (ii) new approach for developing standard data using mathematical modelling
- (iii) coding parts and operations to minimize the estimating computation
- (iv) computer programming algorithm

Chapter III is a case study for computerized estimating. Various steps for developing a computer program for estimating labour data for manufacturing

heat exchangers are presented in depth.

The second part of this dissertation is on multi-project scheduling and control. The object of project scheduling is to plan activities in such a way as to meet the schedule and to optimize the cost. Project schedules are usually divided into two categories:

- (i) single project with no resource constraints
- (ii) multiproject with resource constraints

The first category consists of breaking down the project into many activities and then determining the completion date and the amount of resources required for each activity. Many scheduling techniques are available for that, from the bar chart schedule for simple projects to the advanced, computerized technique such as C.P.M. (Critical Path Method) or PERT (Project Evaluation and Review Technique). The main characteristic for this type of scheduling is that production is not subjected to any external constraints. It is no longer the same for the multiproject scheduling and control under the constraints of resources. The principal feature of this type of scheduling is that production is subject to many random variables such as incoming orders, material shortage, man-power availability, machine capacity, etc. Consequently, production changes continuously.

In Chapter IV, a new approach for multiproject

scheduling and control is presented. The main ideas of this are :

- (i) mathematically modelling the progress of work for each individual project and the total man-hour level required for all projects.
- (ii) monitoring production and optimizing the cost through continuous updatings of the production plan.

Summaries and conclusions indicating highlights of this investigation are presented in Chapter V. Listings of some of the programs are included in the Appendix.

CHAPTER II

COMPUTERIZED COST ESTIMATION

2.1 Function of Cost Estimation

Cost estimates are made for various purposes, the most important of which are :

- (i) Feasibility studies
- (ii) Selection of alternative designs
- (iii) Selection of alternative investments
- (iv) Efficient allocation of funds
- (v) Presentation of bids and contracts

Before funds are allocated for capital expenditures, feasibility investigations must show that the expected profit is sufficient to justify the risk of capital.

Capital cost estimates serve many functions. Although a design problem generally presents many alternatives, the final selection is always based on economic studies. Again, those with money to invest have a choice of investments and decisions are primarily governed by cost studies. Authorization requests from simple acquisitions to large scale expenditures must be based only on accurate cost estimates.

Finally, vendors and contractors are compelled to estimate bids carefully. If the bid is too high, they may not be awarded the job, but if the bid is too low, they may be awarded the job and incur a substantial loss.

2.2 Types of Cost Estimates

During the progress of an engineering project, various types of estimates are involved. At the inception, an approximate estimate only can be justified, but as the project continues and as approval is given at various stages for design and construction expenditures, the type of estimate changes. The steps involved can be described using the definitions of the American Association of Cost Engineers (AACE). They are :

(i) Order of magnitude or Study Estimate .

This estimate is made based on previous similar cost information. Expected error in such an estimate is $\pm 20\%$.

(ii) Preliminary Estimate .

This estimate is used for budget authorization purposes. Expected error here is also $\pm 20\%$

(iii) Definite Estimate .

This estimate is used for project control purposes. Considerable data on the job are available but at a level short of complete drawings and specifications. Here the expected error is $\pm 10\%$

(iv) Detailed Estimate.

Such estimates are used for bidding purposes. They have an expected error of $\pm 5\%$

2.3 Cost of Making Estimates

The cost of making an estimate of a given accuracy can vary over a large range. The figures in table 2.1 given by Bauman (1) show that an estimate of 50% accuracy costs very little, while one of 5% can be very expensive.

2.4 Actual Methods of Cost Estimation

2.4.1 Cost Capacitor Factors

Cost estimates can be approximated for a plant or for equipment where cost data are available for similar projects but of different capacity. In general, costs do not rise in direct proportion to size of plant or equipment. The relationship is generally expressed in the form:

ACCURACY RANGE %	PROJECT COST \$ MILLION					
	0.5	1.0	5	10	15	20
	COST OF ESTIMATE					
-3 To 12	15,000	25,000	45,000	70,000	80,000	120,000
-5 To 15	7,000	13,000	20,000	35,000	45,000	60,000
-10 To 28	2,500	4,500	8,000	13,000	16,000	20,000
-20 To 40	900	1,700	2,800	4,500	6,300	8,000
-30 To 50	500	950	1,500	2,500	3,500	4,500
-40 To 60	300	600	1,000	1,700	2,300	3,000
-50 To 70	250	350	600	900	1,300	1,700

Table 2.1

Cost of Estimate

$$C_2 = C_1 \left(\frac{Q_2}{Q_1} \right)^x$$

where C_2 = desired cost of capacity Q_2

C_1 = known cost of capacity Q_1

The exponent x in the above equation is known as the cost capacity factor. Normally x is about 0.6 and the relationship is referred to as the six-tenths factor rule (2).

Q can be expressed in any consistent units as it enters only as ratio.

Although $x = 0.6$ is an average value for the cost capacitor factor, it usually ranges from 0.2 to 1.0. The 0.6 factor should be used only in the absence of other information. Many other cost capacitor factors can be found in the literature or can be calculated by plotting published data (3,4).

2.4.2 Equipment Installation Ratio

In many cases, a cost is estimated by multiplying one cost by a factor to get another cost. Thus, the cost of a building complete with electrical,

plumbing, heating, ventilation and air-conditioning systems might be estimated by multiplying the cost of the shell by 1.0. Such factors are called ratio cost factors (5) which might be good to an accuracy $\pm 20\%$ when applied to the known cost of key items.

A common use of ratio factors is the estimation of the installed cost of equipment from the purchase cost. Since the installed cost is the sum of the fabrication cost, transportation cost, cost of foundations, construction and connections to service facilities, it is much easier to multiply the fabrication cost by the appropriate factor in order to arrive at the installed cost.

2.4.3 Plant Cost Ratio

Plant Cost Ratio are factors used for obtaining plant cost from major equipment costs. Lang (6) recommended multiplying the delivered cost of equipment by the following factors to obtain the total process plant cost:

3.10 for solid process plants

3.63 for solid-fluid process plants

4.74 for fluid process-plants

Such factors can be used only for order of magnitude estimates because they make no allowance for process variations and other variables that affect costs. Greater accuracy can be achieved by using factors based on the different types of equipment. Hand (7) recommends the following factors:

- 4.0 for fractionating columns, pressure vessels, pumps, and instruments
- 3.5 for heat exchangers
- 2.5 for compressors
- 2.0 for fired heaters, etc.

Wroth (8) gave table 2.2 for obtaining Process Plant Cost Ratio from Individual Equipment.

2.4.4 Determination of Plant Cost by Analytical Procedure

Because of the wide application of computers, there is interest in the use of equations, instead of tables or charts for cost estimation. Hirsch and Glazier (9) developed the following equation, suitable

EQUIPMENT	PROCFSS-PLANT COST RATIO
Blender	2.0
Blowers & Fans	2.5
Compressors	2.3
Ejectors	2.3
Furnaces	2.0
Heat-Fxchangers	4.8
Instruments	4.1
Motors, Electric	8.5
Pumps	6.0
<u>Tanks:</u>	
Process	4.1
Storage	3.5
Fabricated and Field Erected	2.0
Towers	4.0

Table 2.2

Process Plant Cost Ratio From Individual Equipment.

for computer calculation of Costs:

$$I = F \left[A(1 + F_L + F_P + F_M) + B + C \right]$$

where I = total plant cost

A = total purchased equipment cost on fabrication basis less incremental cost for corrosion resistant alloys (in \$ million).

P = Installed equipment cost.

C = Incremental cost of alloy material used only for their corrosion resisting properties.

E = Indirect cost factor representing contractors overhead and profit, engineering, supervision, and contingencies. E is normally assumed to be 1.4.

F_L = Cost factor for field labour; $F_L A$ is the total cost for field labour less supervision, and excluding the labour charges in item B.

F_M = cost factor for miscellaneous items;
 $F_M A$ includes material cost for insulation, instruments, foundations, structural steel, buildings, wiring, painting and the cost of freight and field supervision.

F_P = cost factor for piping material, $F_P A$ is the total cost of piping material including pipe, fittings, valves, hangers, and supports but excluding insulation and installation charges.

The three factors F_L , F_P , F_M are not simple ratios but are defined by the following equations:

$$\log F_L = 0.635 - 0.154 \log A_o - 0.992 \frac{e}{A} + 0.506 \frac{t}{A}$$

$$\log F_P = -0.266 - 0.014 \log A_o - 0.156 \frac{e}{A} + 0.556 \frac{P}{A}$$

$$F_M = 0.344 + 0.033 \log A_o + 1.194 \frac{t}{A}$$

where $A_o = \frac{A}{1000}$

e = total heat exchanger cost less
incremental cost of alloy

f = total cost of field fabricated vessel,
less incremental cost of alloy,
ordinarily all vessels larger than
12 ft in diameter are field erected.

p = total pump plus driver cost less
incremental cost of alloy.

t = total cost of tower shells less
incremental cost of alloy.

These equations are easily solved but the effort
can be reduced by using the method of Walas (10).

2.4.5 Methods for Detailed Estimates

Detailed estimates are made on the basis of
final drawings and specifications. For example, in
piping cost estimates, the total length of all pipes
and the number of fittings can be determined from
drawings, prices can be obtained from catalogues, and
installation costs can be estimated on the basis of

labour per foot of pipe and per fitting. Roberts (11) gives Table 2.3 for Installation Labour Hours for Carbon Steel Piping.

2.5 Comments and Discussions on Existing Methods

- (i) Cost Capacitor Factor is purely empirical with an error of 50%, and is used only when no other information is available
- (ii) Equipment Installation Ratio and Plant Cost Ratio are derived by correlation analysis between purchased cost of major equipment and costs for installation, foundation, supervision, overhead, etc. Capital investment cost estimates by these methods are generally more accurate than estimates by Cost Capacitor Factor method but still with 30% error. All factors given are only average figures. So for a particular plant, errors could be large. For example the process-plant Cost Ratio for heat-

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Nominal pipe size (in)	Welds per Connection		Flange Joint Handling per Flanges		Flanged Valve Handling per Valve		Pipe Handling per Foot of Pipe		Screwed Joints per Connections	
	Std Wt	Extra Heavy	150 lb	300 lb	150 lb	300 lb	Std Wt	Extra Heavy	Mal- leable Iron	Forged Steel
3/4	0.80	0.90	0.6	0.7	0.3		0.7	0.08	0.4	0.6
1	0.95	1.1	0.7	0.8	0.4		0.08	0.09	0.5	0.8
2	1.4	1.7	0.8	1.1	0.7	0.8	0.11	0.14	1.2	2.0
4	2.5	3.0	1.1	1.4	1.3	1.5	0.20	0.25		
6	3.4	4.5	1.3	2.0	1.7	2.6	0.30	0.40		
8	4.0	6.2	1.3	2.5	2.5	3.8	0.40	0.50		
10	5.7	7.4	2.2	3.5	3.5	5.2	0.50	0.65		
12	6.0	8.5	2.2	4.0	4.5	7.5	0.60	0.7		
14	7.0	9.4	2.6	5.0	6.0	10.0	0.65	0.78		
16	7.9	10.5	3.5	6.0	7.0	13.0	0.70	0.85		

Time given is in man-hrs.

Table 2.3

Installation Labour Requirement for Carbon Steel Piping

exchangers is 4.8 according to Table 2.2. Material cost for stainless steel heat exchangers is twice as much as for a similar one made in carbon steel. But the cost for installation is the same for both cases. Therefore, it would be wrong to apply the same factor for every case in question.

(iii) Plant cost by analytical procedure is more satisfactory than these previous methods since derivation of estimates follows logical steps. Further, it provides:

- (a) mathematical modelling for plant cost developed through experience and analysis.
- (b) determination of coefficients in the equation involves statistical techniques.
- (c) testing of cost model is possible by comparing cost calculated to actual known cost of a plant.

The following equation given by Hirsch and Glazier, Section 2.4.4 illustrates basically the above steps :

$$I = F \quad A(1+F_L+F_P+F_M)+B+C$$

In this equation, A is defined as total purchased equipment cost less incremental cost of alloy material. This separation is basically sound since labour cost defined as $F_L A$ does not depend on extra cost due to alloy material. This characteristic is also applied to other cost factors defined in the equation..

- (iv) The basic difficulty in detailed estimating is that estimated cost for every part has to be identified. This requirement is essential not only because error expected must be within $\pm 5\%$ but also for cost control purposes. Present methods for detailed estimating are highly empirical even in most large

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industrial organizations. The estimating standard manual usually consists of tables or charts showing relationships between different variables. Disadvantages of these present methods may be summarized as follows:

- (a) They are time consuming and expensive
- (b) They leave much to the individual judgment and hence are not reliable. Results cannot be always verified

To overcome these shortcomings, the use of computers for estimating seems to be a logical approach and is explained in the following section.

2.6 A New Approach for Computerized Cost Estimation

2.6.1 Formulation of the Estimation Problem

Project cost is usually divided into two main

classes:

- (i) direct cost
- (ii) indirect cost

Direct cost is composed of labour cost and material cost. Indirect cost is composed of engineering, supervision and marketing costs.

It is only necessary to be concerned with estimating the direct cost since indirect cost can be expressed as some fixed percentage of direct cost depending on the type of engineering project. The problem of estimating could then be formulated in the following manner:

Let x_1, x_2, \dots, x_n be the different components of a project. In the construction of a house for example, the final form of the house is defined as the project. The foundation, floor, partitions, heating system, etc are then defined as components. In a mechanical project, components with all their characteristics are usually specified on drawings and on a bill of materials.

Let C_1, C_2, \dots, C_m be different classes of labour. For costing calculations, class of labour is usually known as cost centre. Basic pay rate and percentage of overhead vary with cost centre.

C_{1j} is defined as the labour time in hours in cost centre C_1 for processing component X_j . Suppose L_1 be the cost of labour per hour for cost centre C_1 , then labour cost L_{Bj} for processing component X_j is :

$$L_{Bj} = C_{1j}L_1 + C_{2j}L_2 + \dots + C_{nj}L_n$$

Labour cost for x_1, x_2, \dots, x_n can be expressed in a matrix form:

$$\begin{bmatrix} L_{B1} \\ L_{B2} \\ \dots \\ L_{Bm} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{21} & \dots & C_{n1} \\ C_{12} & C_{22} & \dots & C_{n2} \\ \dots & \dots & \dots & \dots \\ C_{1m} & C_{2m} & \dots & C_{nm} \end{bmatrix} \begin{bmatrix} L_1 \\ L_2 \\ \dots \\ L_n \end{bmatrix}$$

Total labour cost for the project is then

$$\sum_{j=1}^m L_{Bj} = \sum_{j=1}^m \sum_{i=1}^n c_{ij} L_i$$

Let M_1, M_2, \dots, M_p be different classes of material used for the project.

M_{ij} is defined as quantity of material of class M_i expressed in suitable units to process component x_j . Suppose U_i be the unit cost for material of class M_i , then material cost M_{cj} associated with component x_j is

$$M_{cj} = M_{1j}U_1 + M_{2j}U_2 + \dots + M_{pj}U_p$$

Material cost for x_1, x_2, \dots, x_m can then be expressed in a matrix form:

$$\begin{bmatrix} M_{c1} \\ M_{c2} \\ \vdots \\ M_{cm} \end{bmatrix} = \begin{bmatrix} M_{11} & M_{21} & \dots & M_{p1} \\ M_{12} & M_{22} & \dots & M_{p2} \\ \vdots & \vdots & \ddots & \vdots \\ M_{1m} & M_{2m} & \dots & M_{pm} \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ \vdots \\ U_p \end{bmatrix}$$

Therefore, total material cost for the project is

$$\sum_{j=1}^m M_{C_j} = \sum_{j=1}^m \sum_{i=1}^p M_{ij} U_i$$

For man power planning purposes, it is required to know the total labour time required for cost center C_1 . It is simply equal to $\sum_{j=1}^m C_{1j}$. Similarly, total required material of class M_1 is equal to $\sum_{j=1}^m M_{1j}$. For budget screening purposes, it is necessary to divide costs into many structures. For example in housing construction, costs for foundation, partitions, electrical installation, heating system are usually separated.

Suppose $T_1, T_2, \dots, T_r, \dots, T_q$ be q structures of cost. T_r will define on the set X_j , ($j=1, n$) a partition P_r such that for any X_j that belongs to P_r , the cost associated with X_j will belong to T_r . This could be expressed by the following algebraic notation:

$$\forall X_j \in P_r \implies \text{meaning cost associated with } X_j \text{ will belong to } T_r$$

There are also q such partitions P_r corresponding to q structures T_j ($j=1, q$) of cost.

The total direct cost of structure T_r is then given by

$$x_j \left(P_r \right) \sum_{i=1}^n C_{ij} L_i + \sum_{i=1}^p M_{ij} U_i$$

The division of project components into many structures is very useful for estimating similar work or readjusting estimates when some changes have taken place. In such situations, the whole estimating process need not be repeated but only variables affecting the change need be taken into consideration.

In subsequent developments, it is necessary to be concerned only with labour cost since material cost is available once all components of projects are specified.

Estimating labour cost is reduced to evaluation of the matrix:

C_{11}	C_{21}	--	--	C_{n1}
C_{12}	C_{22}	--	--	C_{n2}
--	--	--	--	--
C_{1m}	C_{2m}	--	--	C_{nm}

As defined previously, C_{ij} is labour required to process X_j at cost center C_i . The object of computerized estimating is to evaluate C_{ij} for all i, j by computer given as input data all project components and their characteristics. To make it feasible, standard data for labour calculation must be in the form of algebraic equations rather than tables or charts.

2.6.2 Standard Data Development

There are two methods to develop standard data :

- (i) Direct method
- (ii) Indirect method

2.6.2.1 Direct Method

The direct method consists of the following:

- (a) Time study is used to determine the time required by a qualified and well-trained person working at a normal pace to do a specified task. The result of time study is the time that a person suited for the job and fully trained in the specified method will need to perform the job if he works at a normal or standard tempo. This time is called the standard time for operation.

The equipment needed for time study work consists of timing devices and auxiliary equipment. The devices for measuring time are:

- (1) stop-watch
- (2) motion picture camera (with constant speed motor drive or with a microchronometer in the picture to indicate time). The

auxiliary equipment consists of observation board, tachometer and slide rule.

- (b) Methods-Time-Measurement (MTM) is a system of motion-time standards which was developed from motion picture studies of industrial operations, and the time standard was first published in 1948. This system is defined as a procedure which analyzes any manual operation or method into basic motions required to perform it, and assigns to each motion a predetermined time standard that is determined by the nature of the motion and the conditions under which it is made.
- (c) Worksampling is based on the laws of probability. A sample taken at random from a large group tends to have the same patterns of distribution as the large group itself. Sampling can be used for measuring work as for measuring delays,

idle time and performance. On short cycle, repetitive operations however, time study, elemental time data, or motion data would be usually preferred for establishing time standards. Sampling can be used profitably for measuring long cycle operations, for work schedules where people are employed in groups, and for activities that do not lend themselves to time study.

All above mentioned techniques for data collection and analysis are equally valid. The use of one technique rather than the other depends strictly on circumstances. Once data have been collected, analysed, and standardized time standards can be developed from elemental time data and formulas. In compiling time standards, elemental time is usually divided into two classes:

- (i) constant elements
- (ii) variable elements.

In machine tool work for example, the time for manipulating the machine and for checking and removing the piece is likely to remain constant for each element, provided the size and shape of the piece are within reasonably close limits. The time for making the cut is the variable here. This machine time can often be calculated when power feeds are known. For example, in milling machine work, if the feed of the table in inches per revolution of the cutter is known, it is then a simple arithmetical problem to find the time required to mill a piece of a given length. Allowances must be provided for the length of the piece, for the approach and for the travel of the cutter.

As an example, consider the time for gear cutting given by (12)

$$M = \frac{NL}{FSH}$$

where M = cutting time in minutes.

N = Number of teeth.

L = length of cut.

F = feed in inches per revolution of work.

S \Rightarrow speed of hub in revolutions per minute

H = lead of hub equal to 1 when it is a single lead, equal to 2 when it is a double lead. Handling time for gear cutting is given by Table 2.4.

2.6.2.2 Indirect Method for Developing Standard Data

Direct method for setting time standards is often used when work is repetitive and when work can be measured by observations. When none of these conditions are applicable, indirect methods for setting time standards are used. Indirect methods are usually classified into two categories:

- (i) Statistical Method
- (ii) Mathematical Modelling.

Statistical Method: Regression and correlation techniques are used for estimating the value of one variable when another variable is known.

	<u>Operations</u>	<u>Time in Minutes</u>
1.	Place blank.	0.05 N
	N = number of piece per chucking.	
2.	Place washer - arbour nut.	0.10
3.	Oil center.	0.10
4.	Advance tailstock.	0.03
5.	Lock tailstock.	0.02
6.	Tighten center.	0.04
7.	Loosen arbour nut.	0.06
8.	Unlock tailstock.	0.02
9.	Back tailstock.	0.03
10.	Remove arbour nut - washer.	0.12
11.	Remove gear.	0.02
		<hr/>
		0.84 0.05 N

Table 2.4

Handling Time - Spur gear

(Chucking - Removing)

Example: To determine the relationship between the total labour required to assemble an air-frame sub-assembly and the total number of "hole operation" such as drilling, reaming a hole, placing a rivet, etc.) in the sub-assembly as given by Table 2.5.

For linear regression, the relationship is represented:

$$Y = a + bX$$

$$\text{where } a = \frac{\frac{\sum X^2}{n} \sum Y - \sum X \sum XY}{\frac{\sum X^2}{n} - \frac{(\sum X)^2}{n}}$$

$$b = \frac{\sum XY - \frac{\sum X \sum Y}{n}}{\sum X^2 - \frac{(\sum X)^2}{n}}$$

For the "hole operations", Table 2.5 gives :

$$\sum X = 2,374 \quad , \quad \sum Y = 46.1 \quad \sum X^2 = 786,368$$

$$\sum Y^2 = 27941 \quad \sum XY = 14,512.6$$

<u>Study</u>	<u>Total Number of Hole Operation</u>	<u>Total Hrs.</u>
A	236	5.1
B	80	1.7
C	127	3.3
D	445	6.0
E	180	2.9
F	343	5.9
G	305	7.0
H	488	9.4
I	170	4.8

Table 2.5

Labour Hrs. for "Hole Operation" in Air Frame Sub-Assembly

Therefore,

$$a = \frac{786,368 \times 46.1 - 2,374 \times 14,512.6}{9 \times 786,368 - (2,374)^2} = 1.245$$

$$b = \frac{9 \times 14,512.6 - 2,374 \times 46.1}{9 \times 786,368 - (2,374)^2} = .0147$$

The equation for the line of regression thus becomes:

$$Y = 1.245 + .0147X$$

Application of regression analysis for setting time is very limited since it can be used when only two variables are involved, even so, the calculation is usually very long. For multivariable relationships, formulas for regression analysis are exceedingly complex. Another reason which does not favor this statistical technique for setting time standards is that it does not permit a causal interpretation or an insight understanding of the manufacturing relationships.

Mathematical Modelling for Setting Time Standards:

This may be the most suitable technique for developing time formulas for estimating purposes. The general procedure is as follows:

- (i) All manufacturing steps for processing a component must be identified and listed in sequence.
- (ii) At each step, main variables (component characteristics) which affect manufacturing time are identified.
- (iii) For each manufacturing operation, a mathematical model for labour time is established as a function of the identified variables.
- (iv) Time formulas are classified according to cost centers.
- (v) All time formulas for the same cost center are added to give a more general time formula.
- (vi) Time constants and coefficients are determined by comparing the time values measured by the direct methods (time study, past data, etc.)

Mathematical modelling also can be used to verify the validity of a given standard data.

For example, in Table 2.3 given by Robert (11) the labour for making butt-weld connections is almost proportional to the size of the pipe. This is illustrated in Figure 2.1. It is required to verify the validity of this time standard:

The time given for butt-weld connection is composed of 3 elements:

- (i) cutting pipes and preparing edges.
- (ii) fitting pipes and tackwelding
 connection.
- (iii) welding.

By mathematical modelling, time for these operations will be determined as follows:

The time t_c for cutting and preparing edges is proportional to the section of the pipe or to the product DT where D is the average diameter and T is the wall thickness. It can then be written as:

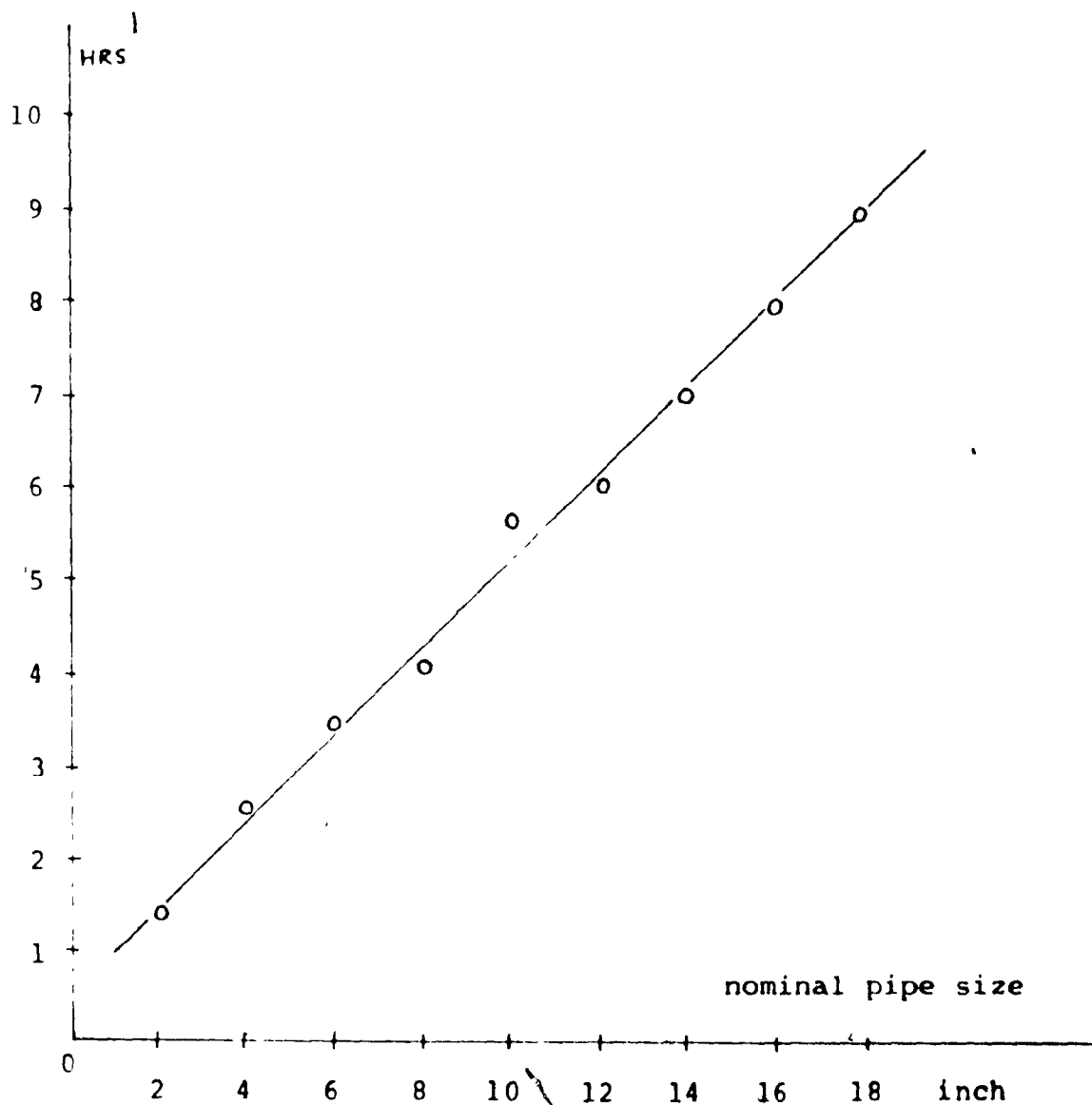


Fig. 2.1

Relationship Between Labour Time and Pipe Size to Make
Butt-Weld Connection Given by Table 2.3.

$$t_c = K_1 DT + C_1$$

where K_1 is the constant of proportionality

C_1 is the constant for start-up

The time t_f for fitting pipes and tackwelding connection is proportional only to the diameter D of the pipe or

$$t_f = K_2 D + C_2$$

The time t_w for welding butt-weld connection is proportional to the volume of weld to be deposited or to the product DT^2 .

Therefore,
$$t_w = K_3 DT^2 + C_3$$

Then the total time t for making a butt-weld connection is:

$$\begin{aligned} t &= t_c + t_f + t_w \\ &= (K_1 DT + C_1) + (K_2 D + C_2) + (K_3 DT^2 + C_3) \\ &= K_3 DT^2 + K_1 DT + K_2 D + (C_1 + C_2 + C_3) \end{aligned}$$

Let $K_4 = C_1 + C_2 + C_3$; Then,

$$t = K_3 DT^2 + K_1 DT + K_2 D + K_4$$

If the wall thickness of pipe is the same for all pipe sizes, then t will be proportional to the diameter of the pipe. Such is not the case since the wall thickness varies with the size of pipe as given in Table 2.6. Therefore, the time standards for butt-weld connections given by Table 2.3 are not reliable. Error involved can be significant as the diameter of pipe increases.

Constants K_1 , K_2 , K_3 , K_4 of the equation for t may be determined as follows:

<u>Nominal Pipe Size</u> (Inches)	<u>Wall Thickness</u> (Inches)
3/4	0.113
1	0.133
1 1/4	0.140
1 1/2	0.145
2	0.154
2 1/2	0.203
3	0.216
4	0.237
6	0.280
8	0.322
10	0.365
12	0.375
14	0.375
16	0.375
18	0.375

Table 2.6

Let t_1, t_2, t_3, t_4 be actual times recorded for butt-weld connection for pipe of diameter D_1, D_2, D_3, D_4 respectively. Let T_1, T_2, T_3, T_4 be the wall thickness corresponding to diameter D_1, D_2, D_3, D_4 . Following relations may then be written:

$$t_1 = K_3(D_1 T_1^2) + K_1(D_1 T_1) + K_2(D_1) + K_4$$

$$t_2 = K_3(D_2 T_2^2) + K_1(D_2 T_2) + K_2(D_2) + K_4$$

$$t_3 = K_3(D_3 T_3^2) + K_1(D_3 T_3) + K_2(D_3) + K_4$$

$$t_4 = K_3(D_4 T_4^2) + K_1(D_4 T_4) + K_2(D_4) + K_4$$

This is a system of 4 linear equations with unknown variables K_1, K_2, K_3, K_4 . By repeating the calculation for different set of diameters, average values for K_1, K_2, K_3, K_4 can be determined.

2.6.3 Computerized Estimating

When all time formulas f_i have been determined for all components, they shall be grouped on the basis of

cost enters C_j as shown in the matrix given in Table 2.7.

The usual method of writing a computer program for estimating labour time in this case is to make a sub-program for each time formula and to give a code for each component. For example, if component 1 is given code 1, component 2 is given code 2, etc., we may have the following main program (excluding input-output statements).

```

Read, component, code,  $p_1, p_2, \dots, p_m$ 

Go to (1, 2, 3, \dots, 11) code

1   $C_2(1) = f_1(p_1, p_2, \dots, p_m)$ 

    $C_3(1) = f_4(p_1, p_2, \dots, p_m)$ 

    $C_4(1) = f_5(p_1, p_2, \dots, p_m)$ 

    $C_5(1) = f_6(p_1, p_2, \dots, p_m)$ 

    $C_6(1) = f_9(p_1, p_2, \dots, p_m)$ 

Go to x

2   $C_2(2) = f_2(p_1, p_2, \dots, p_m)$ 

    $C_3(2) = f_3(p_1, p_2, \dots, p_m)$ 

```

$$C_4(2) = f_5(p_1, p_2, \dots, p_m)$$

Go to x

$$3 \quad C_1(3) = f_1(p_1, p_2, \dots, p_m)$$

$$C_3(3) = f_4(p_1, p_2, \dots, p_m)$$

Go to x

.....

$$11 \quad C_3(11) = f_4(p_1, p_2, \dots, p_m)$$

$$C_5(11) = f_5(p_1, p_2, \dots, p_m)$$

x

.....

Note:

$C_i(j)$ is defined as time required to process component j at cost center i and p_1, p_2, \dots , are component characteristics such as length, width, diameter, etc.

If a time formula is executed more than 3 times, it will be computed by sub-programs as follows:

Function sub-program

Function $f_i(p_1, p_2, \dots, p_m)$

$f_i(p_1, p_2, \dots, p_m) = \dots$ (time formula)

Return

End

Accordingly, 4 sub-programs are required for f_1, f_2, f_4, f_5 . This method of computer programming is acceptable when the number of time formulas and the number of components is relatively small. In the case of a complex estimating problem involving a large number of components and time formulas, this method is very cumbersome and might not be workable as explained below:

Suppose m be the number of components, p be the average number of cost centers per components and n be the number of time formulas, then the number of programming statements is:

(i) mp executable statements $\left[\text{type } C_i(j) = f_r(p_1, p_2, \dots, p_m) \right]$

	C ₁	C ₂	C ₃		C ₄	C ₅			C ₆
	f ₁	f ₂	f ₃	f ₄	f ₅	f ₆	f ₇	f ₈	f ₉
Component 1		x		x	x		y		x
Component 2		x	x		x				
Component 3	x			x					
Component 4	x		x						
Component 5					y	x			
Component 6	x	x					x		x
Component 7		x		x	x			x	
Component 8	x	x					x		
Component 9		x	x		x				
Component 10	x						y		
Component 11				x		x			
	5	6	3	4	5	2	4	1	2

Note: C₁, C₂, . . . , C₆ designates cost centers

f₁, f₂, . . . , f₉ designates time formulas.

Table 2.7

Matrix of Applicable Time Formulas

- (ii) m control statements (type Go to X)
- (iii) n sub-programs for time formulas.

Therefore, for efficient programming, the number of program statements and of sub-programs must be reduced to a minimum. This concept is explained further in the next section.

2.6.3.1 Programming for the Shortest Path Computation

The basic idea of this approach is that components should not be coded randomly, but should be classified into families and groups and then coded accordingly. The first step is illustrated by using the same example given in Table 2.7.

	c ₁	c ₂	c ₃		c ₄		c ₅		c ₆
	f ₁	f ₂	f ₃	f ₄	f ₅	f ₆	f ₇	f ₈	f ₉
Component 1		x		x	x		x		x
Component 2		x	x		x				
Component 3	x			x					
Component 4	x		x						
Component 5					x	x			
Component 6	x	x					x		x
Component 7		x		x	x			x	
Component 8	x	x					x		
Component 9		x	x		x				
Component 10	x						x		
Component 11				x		x			
	5	6	3	4	5	2	4	1	2

The algorithm is as follows:

- (i) List frequency of use for each time formula.
Determine the formula having the highest frequency. In case of more than one highest frequency, select any of them.
- (ii) Group together all components sharing this formula by row permutation, leave all other components in the same order.

The original matrix will then be transformed into the following matrix.

Family 1

		c ₁	c ₂	c ₃		c ₄	c ₅			c ₆
		f ₁	f ₂	f ₃	f ₄	f ₅	f ₆	f ₇	f ₈	f ₉
Component 1			X		X	X		X		X
Component 2			X	X		X				
Component 6		X	X							
Component 7			X		X	X			X	
Component 8		X	X					X		
Component 9			X	X		X				
		2	-	2	2	4	0	3	1	2
Component 3		X			X					
Component 4		X		X						
Component 5						X	X			
Component 10		X					X			
Component 11					X		X			
		3	0	1	2	1	3	0	0	0

The same procedure is repeated for the remaining components and then for each family until no further grouping is possible. The final partitioning yields:

				C ₁	C ₂	C ₃		C ₄	C ₅			C ₆	
				f ₁	f ₂	f ₃	f ₄	f ₅	f ₆	f ₇	f ₈	f ₉	
Family 1	Group 11	112	111	Component 1		X		X	Y		Y		X
			1112 1111	Component 7		X		Y	X			Y	
		122 121	112	Component 2		X	X						
			122 121	Component 9		X	X						
	Group 12	122 121	122 121	Component 6	X	Y							
			122 121	Component 8	X	X					X		
Family 2	21	22	21	Component 3	X			X					
			22	Component 4	X		X						
			23	Component 10	X					X			
Family 3	31	33	31	Component 5				X	X				
			33	Component 11				X		X			

As a result of this matrix, components will have more than one code. The first code designates the family, the second designates the group, the third designates the sub-group level 1, the fourth designates the sub-group level 2, etc. The coding for the above example is shown in Table 2.7

	Code 1	Code 2	Code 3	Code 4
Component 1	1	11	111	1111
Component 7	1	11	111	1112
Component 2	1	11	112	-
Component 9	1	11	112	-
Component 6	1	12	121	
Component 8	1	12	122	
Component 3	2	21		
Component 4	2	22		
Component 10	2	23		
Component 5	3	31		
Component 11	3	32		

Table 2.8

Component Coding for the Shortest Path Computation.

The corresponding computer program may then be written as follows:

```

Do      1000      I = 1, N

Read component (I), Code 1(I), Code 2(I), Code 3(I),
               Code 4(I),

P1(I), P2(I), . . . , Pm(I).

m1 = Code 1(I)

m2 = Code 2(I)

m3 = Code 3(I)

m4 = Code 4(I)

Go to (1, 2, 3) m1

1  C2(I) =  $\int_2 [P_1(I), P_2(I) \dots, P_m(I)]$ 

Go to (11, 12) m2

11 C4(I) =  $\int_5 [P_1(I), P_2(I) \dots, P_m(I)]$ 

```

Go to (111, 112) m_3

$$111 \quad C_3(I) = f_4 [P_1(I), P_2(I) \dots, P_m(I)]$$

Go to (1111, 1112) m_4

$$1111 \quad C_5(I) = f_7 [P_1(I), P_2(I) \dots, P_m(I)]$$

$$C_6(I) = f_4 [P_1(I), P_2(I) \dots, P_m(I)]$$

Go to 1000.

$$112 \quad C_3(I) = f_3 [P_1(I), P_2(I) \dots, P_m(I)]$$

Go to 1000.

$$12 \quad C_1(I) = f_1 [P_1(I), P_2(I) \dots, P_m(I)]$$

$$C_5(I) = f_7 [P_1(I), P_2(I) \dots, P_m(I)]$$

Go to (121, 122) m_4 .

$$121 \quad C_6(I) = f_9 [P_1(I), P_2(I) \dots, P_m(I)]$$

122 Go to 1000.

2	Go to (21, 22, 23) m_2
	$C_3(I) = f_4 [P_1(I), P_2(I) \dots, P_m(I)]$
	Go to 1000.
23	$C_5(I) = f_6 [P_1(I), P_2(I) \dots, P_m(I)]$
	Go to 1000.
3	$C_5(I) = f_6 [P_1(I), P_2(I) \dots, P_m(I)]$
	Go to (31, 32) m_4
31	$C_3(I) = f_4 [P_1(I), P_2(I) \dots, P_m(I)]$
	Go to 1000.
32	$C_5(I) = f_5 [P_1(I), P_2(I) \dots, P_m(I)]$
1000	Continue.

The result of data reduction obtained by this program is as follows (excluding input and output statements).

	Random Coding	Optimum Coding
Executable statements type $C_q(1) = \{ \}$	33	17
Control statements type Go to	11	15
Sub-programs	5	0

As an application of the new approach for computerized cost estimation, the next chapter shows the development of a computer program for estimating time for manufacturing heat exchangers. This example is chosen because it is of a complex nature and involves fully all the various aspects of labor estimation described previously.

CHAPTER III

A CASE STUDY:

COMPUTERIZED TIME ESTIMATION FOR MANUFACTURING

HEAT EXCHANGERS

3.1 Description of Heat Exchanger

Heat exchangers, as the name implies, transfer heat from one substance to another. There are 3 basic modes of heat transfer :

- (1) conduction
- (2) radiation
- and (3) convection.

In actual heat exchangers, all three usually come into play, in varying degrees. The most common of all heat exchangers is the shell and tube type where the main mechanisms of heat transfer are conduction and convection.

These heat exchangers are used extensively in the Processing and Power generation industries. In particular they are employed in :

- (1) feed-water heating.
- (2) lubricating-oil cooling.
- (3) fuel oil heating.
- (4) service-water heating.
- (5) compressed-air and gas cooling.
- (6) heat reclaiming from blow-down and other wastes.
- (7) engine cooling.

- (8) transformer-oil cooling.
- (9) refrigeration evaporators or chillers and many others.

A heat exchanger is selected after careful considerations. To design a unit for a particular application, manufacturers need the following information :

- (1) heat load, Btu per hr.
- (2) total quantity flow of fluids entering exchanger, lb. per hr.
- (3) specific heat, thermal conductivity, viscosity and specific gravity of fluids, in appropriate units.
- (4) temperature into and out of exchanger, °F
- (5) operating pressure of shell and tube fluids, psig
- (6) allowable pressure drop for each fluid,
- (7) cleanliness of fluids, sediment or contaminant carried.
- (8) available installation space.
- (9) data on corrosive conditions that may affect exchanger material.
- (10) type of unit required.
- (11) horizontal or vertical installation, etc.

Main assemblies and parts of a typical heat exchanger are shown in Fig. 3.1(13). Some idea of the diversity of types could be gained through Heat Exchanger Nomenclature, Fig. 3.2(13).

A wide variety of materials is available for exchanger construction, type selected for each part depends on operating conditions, particularly on their corrosion resistance. TEMA (Tubular Exchanger Manufacturers Association) standards list the following materials:

Shells: Pipe of carbon steel or alloy steel. Plate of carbon, carbon-silicon, molybdenum, cast iron.

Flange: Forged steel, forged alloy steel.

Channels, Channel Covers, Shell Covers, Floating Heads.

Cast steel, cast alloy steel, cast brass, any material used for shell.

Tube Sheets: Alloys of ~~copper~~ or iron.

Baffles-Support Plates: Steel, non-ferrous material.

Tubes: Carbon and Carbon moly steels, alloy steels, copper, copper alloys.

Tie Rods-Spacers: Same as baffles or tubes.

Nozzles: Forged carbon steel, forged alloy steel.

3.2 Fabrication of Heat Exchangers

Fig. 3.3, Fig. 3.4, Fig. 3.5 show the basic sequence of manufacturing operations for constructing some parts and assemblies of a heat exchanger of type AET of Fig. 3.2. For another type, sequence of operations might be different depending on its main features.

3.3 Parameters Affecting Manufacturing Time

For a particular type of heat exchanger, size and material of its components vary over a large range since the final dimensions of a heat exchanger depend on all the factors mentioned in Section 3.1. For example, materials and thickness for shell barrel is selected on the basis of corrosion resistance, and operating pressure; size of nozzle on the basis of quantity flow of fluids entering heat exchanger given in lb per hr. Therefore, time for manufacturing a particular heat exchanger will also vary considerably. The first step in developing standard data for estimating labour through mathematical modelling is to identify parameters affecting time for each manufacturing operation. Table 3.1 and Table 3.2 illustrate examples for this purpose.

N-2 NOMENCLATURE OF HEAT EXCHANGER COMPONENTS

For the purpose of establishing standard terminology, Figure N-2 illustrates various types of heat exchangers. Typical parts and connections, for illustrative purposes only, are numbered for identification in Table N-2.

TABLE N-2

1 Stationary Head - Channel	20 Slip on Backing Flange
2 Stationary Head - Bonnet	21 Floating Head Cover - External
3 Stationary Head Flange - Channel or Bonnet	22 Floating Tubesheet Skirt
4 Channel Cover	23 Packing Box Flange
5 Stationary Head Nozzle	24 Packing
6 Stationary Tubesheet	25 Packing Follower Ring
7 Tubes	26 Lantern Ring
8 Shell	27 Tie Rods and Spacers
9 Shell Cover	28 Transverse Baffles or Support Plates
10 Shell Flange - Stationary Head End	29 Impingement Baffle
11 Shell Flange - Rear Head End	30 Longitudinal Baffle
12 Shell Nozzle	31 Pass Partition
13 Shell Cover Flange	32 Vent Connection
14 Expansion Joint	33 Drain Connection
15 Floating Tubesheet	34 Restraint Connection
16 Floating Head Cover	35 Support Saddle
17 Floating Head Flange	36 Lifting Lug
18 Floating Head Packing Device	37 Support Bracket
19 Split Seal Ring	38 Weir
	39 Liquid Level Connection

FIGURE N-2

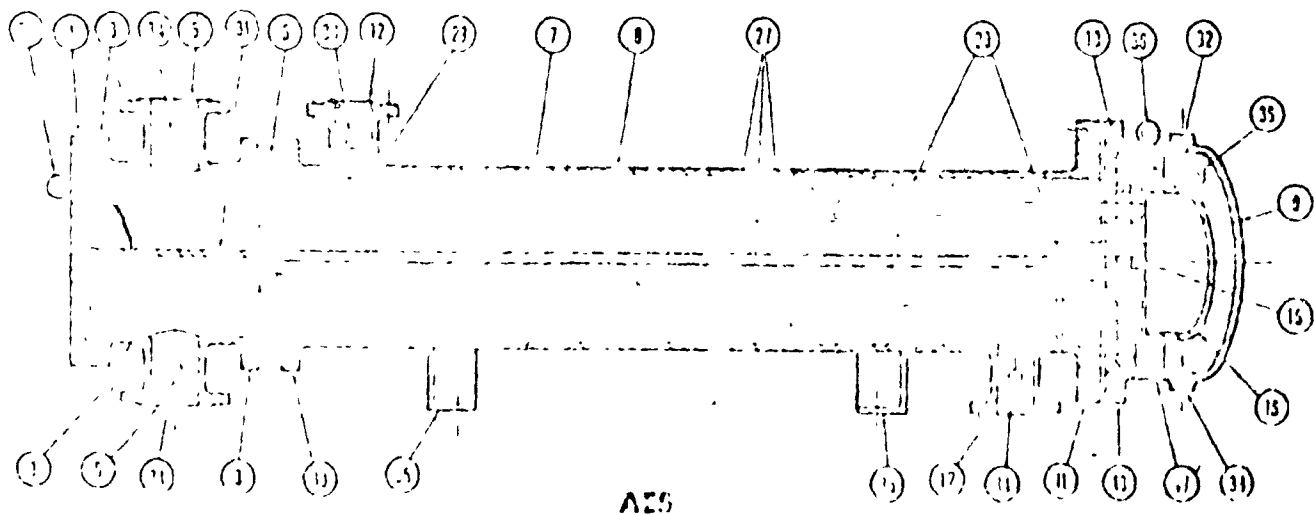


Fig. 3.1 Nomenclature for heat exchanger components.


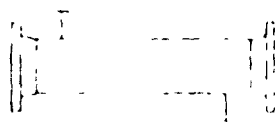
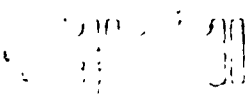

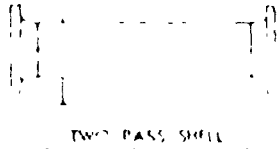
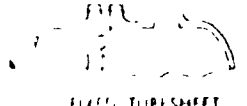

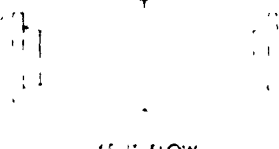
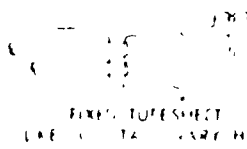
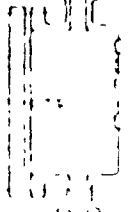
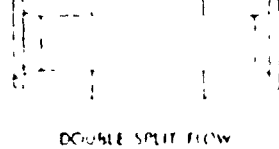
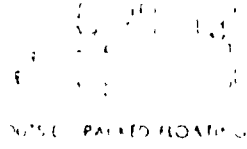

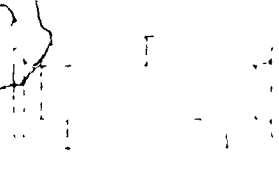
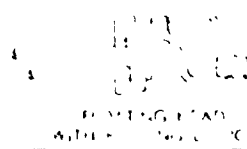
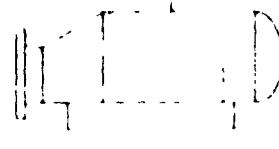
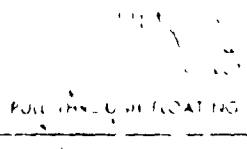
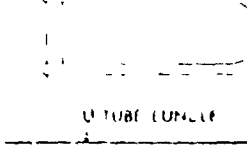
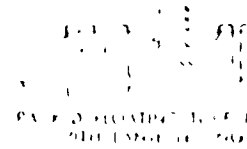
	FRONT END STATIONARY HEAD TYPES		SHELL TYPES		REAR END HEAD TYPES
A	 CHANNEL COVER AND REMOVABLE COVER	E	 ONE PASS SHELL	L	 FIXED TUBESHEET LIKE A STATIONARY HEAD
B	 BONNET INTERNAL COVER	F	 TWO PASS SHELL WITH U-TUBE AND BAFFLE	1A	 FIXED TUBESHEET LIKE A STATIONARY HEAD
C	 REMOVABLE TUBE BUNDLE ONLY	G	 SPLIT FLOW	N	 FIXED TUBESHEET LIKE A STATIONARY HEAD
D	 FIXED TUBESHEET LIKE A STATIONARY HEAD	H	 DOUBLE SPLIT FLOW	P	 FIXED TUBESHEET LIKE A STATIONARY HEAD
D	 SPECIAL FRONT END TUBE BUNDLE	J	 DIVIDED FLOW	S	 FIXED TUBESHEET LIKE A STATIONARY HEAD
		K	 BOTTLE TYPE COOLER	T	 PULL THROUGH FLOATING HEAD
				U	 U-TUBE BUNDLE
				V	 FIXED TUBESHEET LIKE A STATIONARY HEAD

Fig. 3.2 Nomenclature for Heat Exchangers.

Shell Barrel

Shell Flange

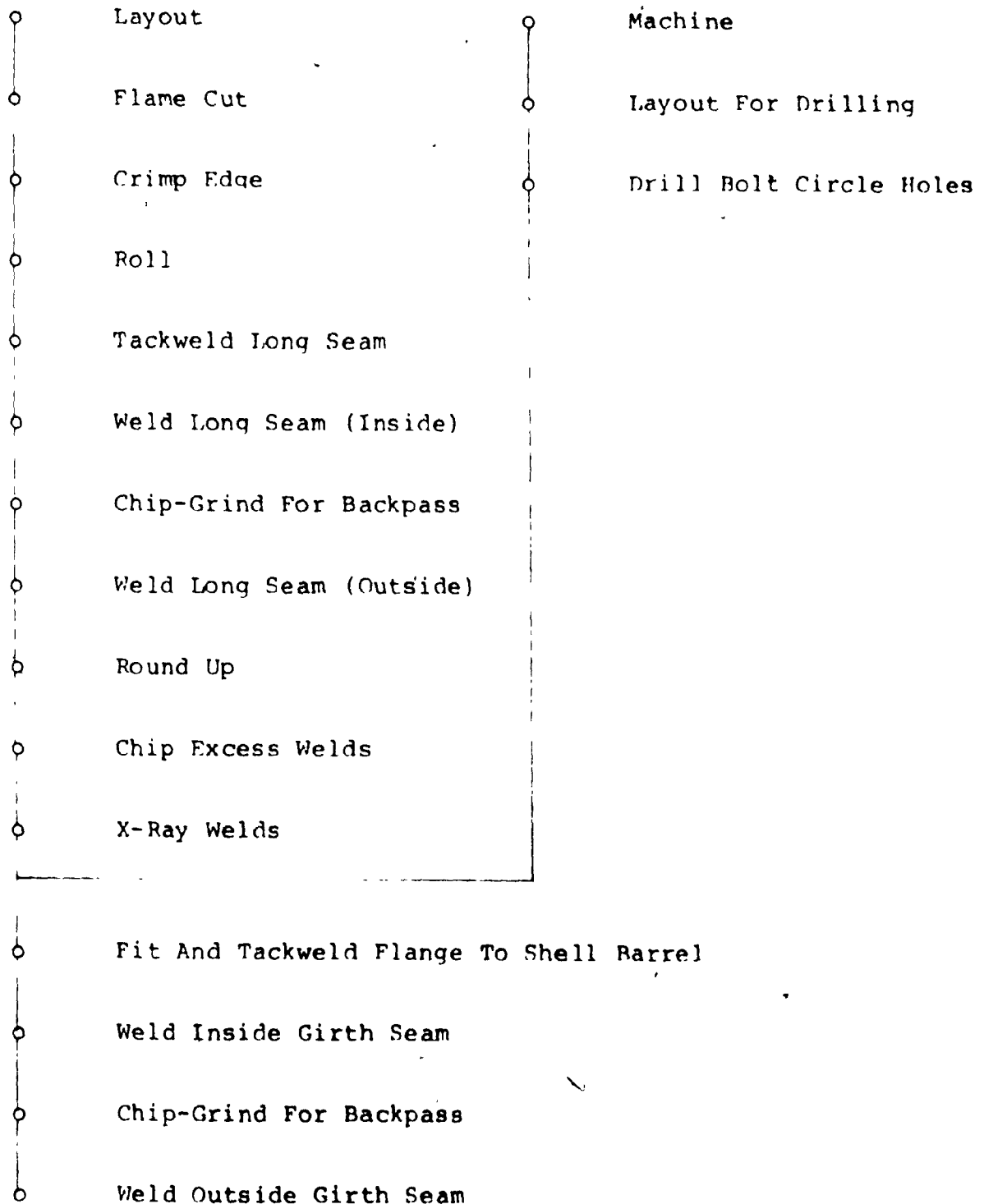


Fig. 3.3 Manufacturing Operations Sequence For A Shell Assembly.

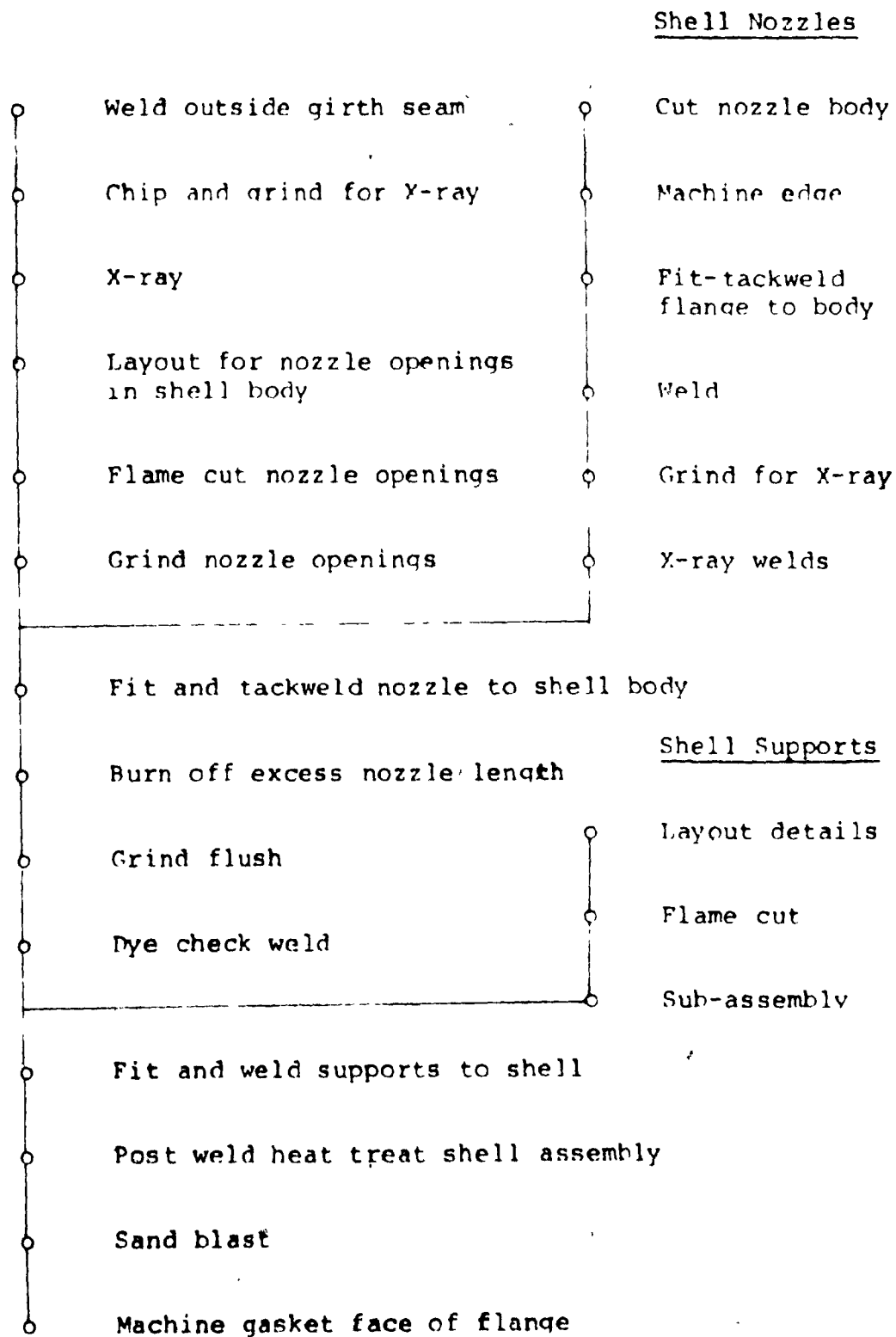


Fig. 3.3 (Continued)

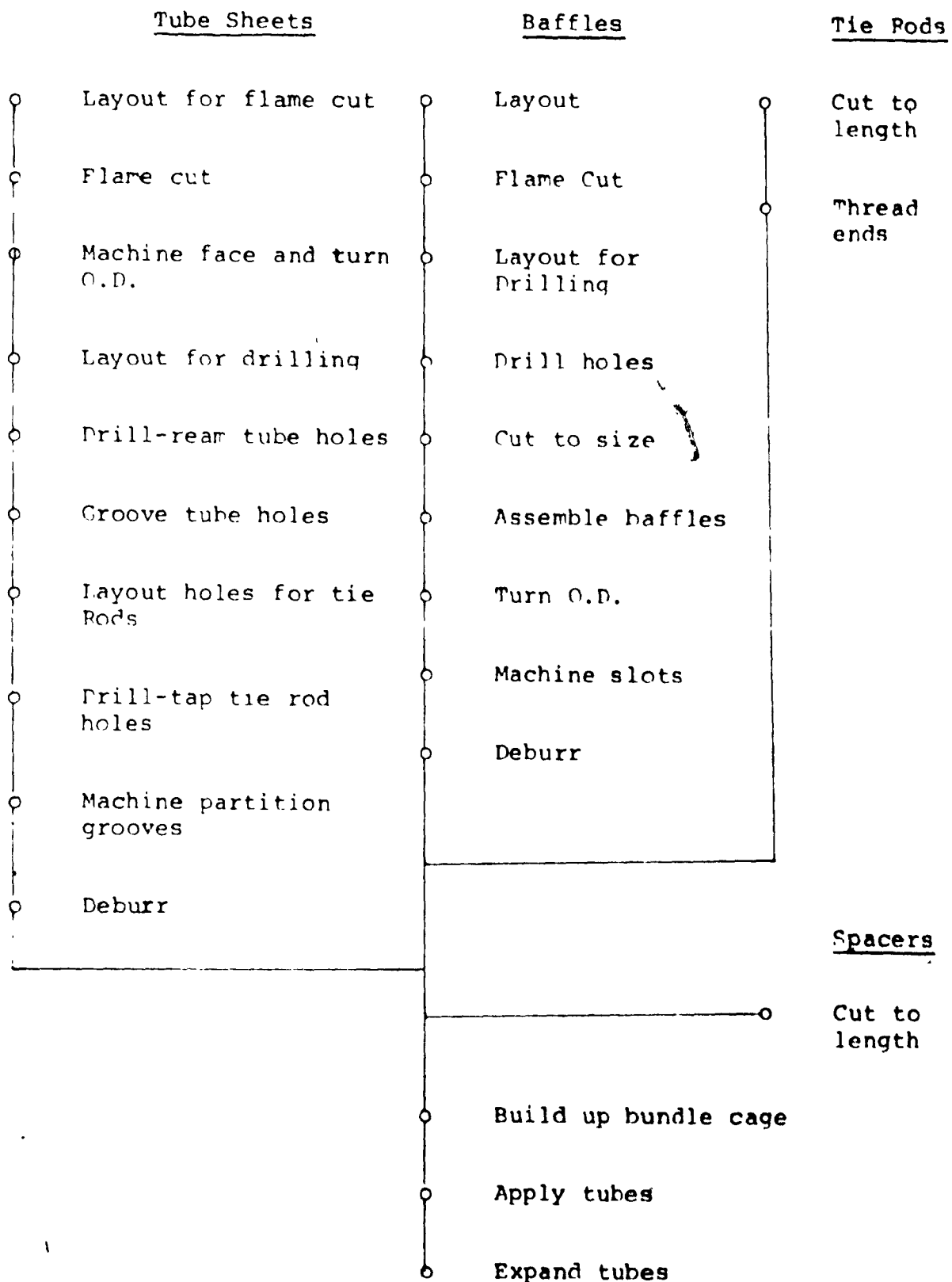


Fig. 3.4 Manufacturing Operations Sequence for Assembly of Bundles.

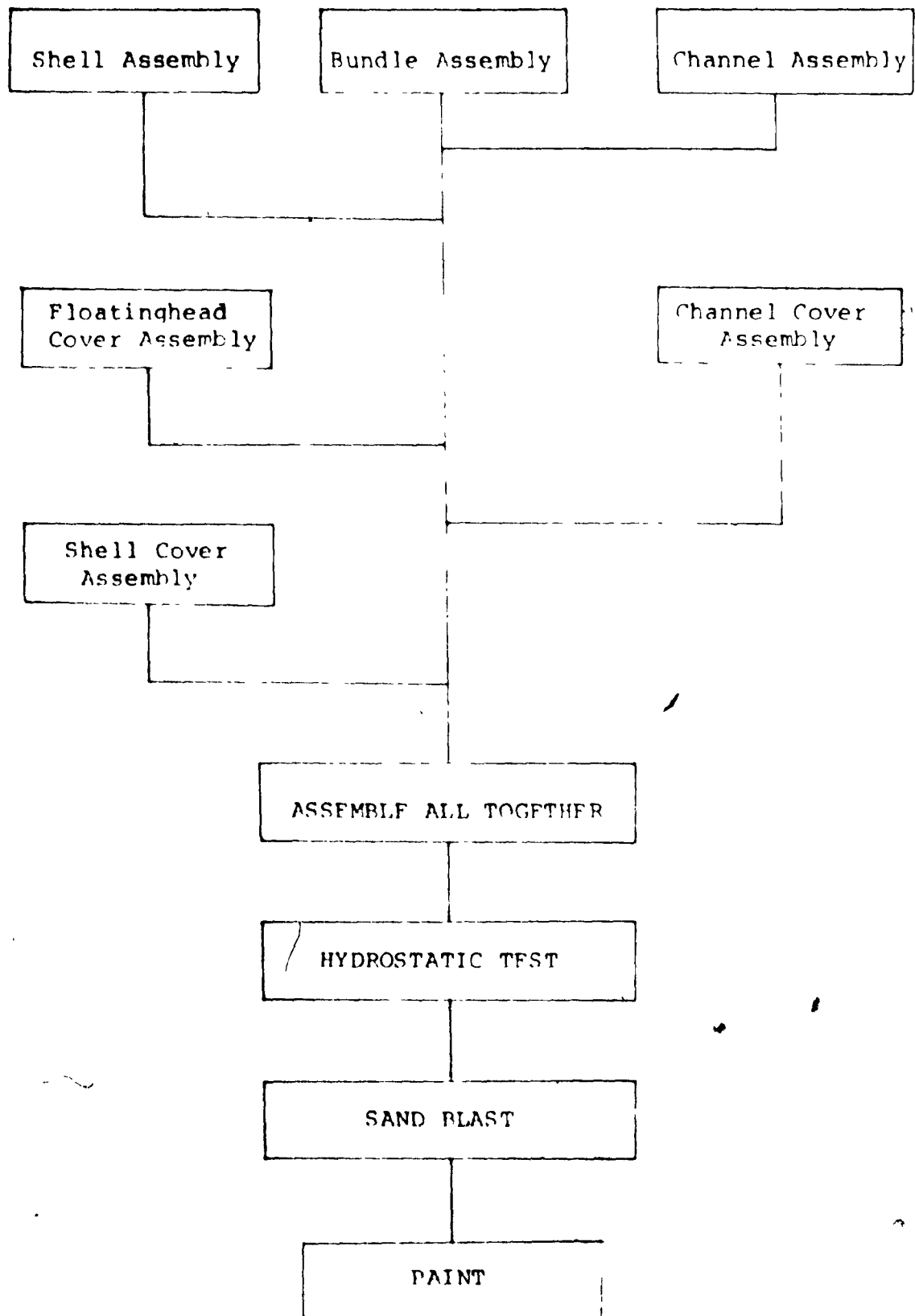
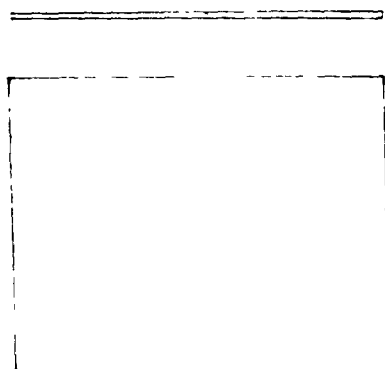
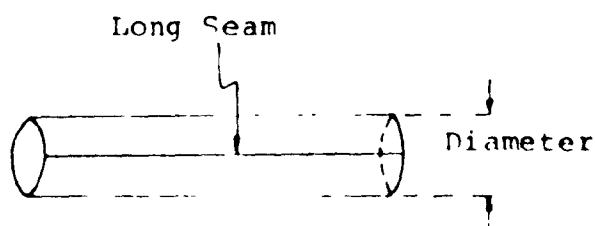


Fig. 3.5 Manufacturing Operations Sequence of Final Assembly and Testing.

Thickness



Length



Shell Barrel To Be Made From A Plate

<u>Operations</u>	<u>Parameters Affecting Labour Time</u>
(1) Layout contour.	length, width
(2) Flame cut.	length, width, thickness
(3) Plane edge.	length, width, thickness
(4) Crimp edge.	length, thickness
(5) Roll.	length, width, thickness
(6) Tackweld long seam.	length
(7) Weld inside long seam.	length, thickness, material
(8) Gauge backpass.	length, thickness
(9) Grind backpass.	length, thickness
(10) Weld outside long seam.	length, thickness, material
(11) Pound up	diameter, thickness, length
(12) Chip inside long seam.	length, thickness
(13) Grind outside for X-ray.	length, thickness

Table 3.1: Parameters Affecting Time To Make A Shell Barrel.

<u>Operations</u>	<u>Parameters Affecting Labour Time</u>
(1) Layout contour.	Thickness, diameter
(2) Flame cut.	Thickness, diameter of tube sheet
(3) Machine face and outside diameter.	Diameter, thickness, material
(4) Layout for drilling.	Number of tube holes, number of gasket grooves
(5) Drill-ream tube holes.	Number of tube holes, diameter of tube hole, thickness of tube sheet material
(6) Groove tube holes	Number of tube holes- diameter of hole & material
(7) Layout holes for tie rods.	Number of tie rods.
(8) Drill and tap tie rod holes.	Number of rod holes
(9) Machine gasket grooves	Number of grooves, diameter of tube sheet
(10) Deburr tube sheet.	Number of holes, thickness and diameter of tube sheet

Table 3.2 Parameters Affecting Time to Make a Tube Sheet.

3.4 Standard Data Development

After analyzing all operations and determining all factors which affect manufacturing time, standard data are developed using the mathematical modelling technique which consists of two steps:

- (i) mathematical relationship between labour time for an operation and its time parameters is assumed to be a certain algebraic function with some unknown time coefficients. The type of function depends on the operation and manufacturing technique.
- (ii) time coefficients will be determined after some statistical data for the operation have been collected and analysed.

Table 3.2 shows the mathematical modelling for labour time to perform various operations for making a shell barrel using the following nomenclature.

C_i time constant for start up

K_i time coefficient

D diameter of shell

L = length of shell

T = thickness of shell plate

W = width of developed shell plate

3.5 Consolidating Time Formulas By Cost Centers

In a detailed estimate, it is required to estimate labour time for each component on the basis of cost center. The reason is mainly for accounting purposes since labour rate of pay and overhead cost are not uniform. Therefore, labour time for operations at same cost center are added up to yield a single time. The end result is that for each part or sub-assembly, there will be only one time formula per cost center. In fabricating a shell barrel, there are 3 cost centers to cover 11 operations of Table 3.3. This is shown on Table 3.4.

<u>Operations</u>	<u>Time Formula</u>	<u>Explanation</u>
(1) Layout contour	$t = K_1(L+W) + C_1$	time is proportional to: developed contour
(2) Flame cut	$t = K_2^T(I+W) C_2$	developed contour section
(3) Plane edge (contour)	$t = K_3T(L+W) C_3$	developed contour section
(4) Crimp edge	$t = K_4LT + C_4$	longitudinal section
(5) Roll	$t = K_5LTW + C_5$	weight
(6) Tackweld	$t = K_6L + C_6$	length of long seam
(7) Weld inside	$t = K_7LT^2 + C_7$	volume of weld
(8) Gauge backpass	$t = K_8LT + C_8$	cross section of seam
(9) Grind backpass	$t = K_9IT + C_8$	cross section of seam
(10) Weld inside	$t = K_{10}LT^2 + C_{10}$	volume of weld
(11) Round up	$t = K_{11}\frac{LT^2}{D} + C_{11}$	volume of weld

Note: Time coefficients K_1, K_2, \dots, K_{12} and C_1, C_2, \dots, C_{11} are to be determined by work measurement technique: time study, records of actual time spent, statistical analysis.

Table 3.3: Mathematical Modelling for Labour Time to Make a Shell Barrel.

<u>Operations</u>	<u>Cost Center 1</u>	<u>Cost Center 2</u>	<u>Cost Center 3</u>
(1) Layout		$K_1 (L+W) + C_1$	
(2) Flame cut		$K_2 T (L+W) + C_2$	
(3) Plane bevel		$K_3 T (L+W) + C_3$	
(4) Crimp	$K_4 LT + C_4$		
(5) Roll	$K_5 LTW + C_5$		
(6) Tackweld		$K_6 L + C_6$	
(7) Weld inside			$K_7 LT^2 + C_7$
(8) Gauge backpass		$K_8 LT + C_8$	
(9) Grind backpass		$K_9 LT + C_9$	
(10) Weld outside			$K_{10} LT^2 + C_{10}$
(11) Round up		$K_{11} \frac{LT^2}{D} + C_{11}$	

Time at cost center 1 = $IT(K_4 + K_5 W) + C_4 + C_5$

Time at cost center 2 = $K_1 (L+W) + (K_1 + K_2) T (L+W) + C_1 + C_2 + C_3 + C_6 + C_8 + C_9 + C_{11}$

$(K_2 + K_3 + K_8 + K_9) LT + K_{11} \frac{LT^2}{D}$

Time at cost center 3 = $LT^2 (K_7 + K_{10}) + C_7 + C_{10}$

Table 3.4 Grouping time formulas on the basis of cost centers.

3.6 Coding of Heat Exchanger Components and Assemblies

After all time formulas are developed, components and sub-assemblies are classified into families and groups following the procedure explained in Chapter II, Section 2. There are in total 41 families, each again divided into many groups and sub-groups to cover 183 parts and assemblies of various types of heat exchangers. An example is shown below :

<u>Part Name</u>	<u>Family Code</u>	<u>Group Code</u>	<u>Sub-Group Code</u>
Shell barrel (carbon steel)	1	1	
Shell barrel (stainless steel)	1	1	1
Channel barrel (carbon steel)	1	1	
Channel barrel (stainless steel)	1	1	1
Skirt barrel (carbon steel)	1	1	
Skirt barrel (stainless steel)	1	1	1
Impact plate (carbon steel)	1	2	
Impact plate (stainless steel)	1	2	
Shell cover assemblies (carbon steel)	2	1	
Shell cover assemblies (stainless steel)	2	1	1

3.7 Computer Program for Time Estimation

The listing of the computer program is shown on Appendix I. The main features of this program are:

- (1) All components and assemblies of a heat exchanger are read into computer memory - parts and assemblies are then sorted into families. Number of parts per family is recorded.
- (2) No sub-program is required. Computation begins with all parts of family 1, then with family 2 and so on. Computation is on a straight line basis.
- (3) Estimate time for each part is given at each cost center.

A sample of computer print-out is shown on the following page.

3.8 Input Format for Data

Input format will be prepared on the basis of type of heat exchanger. All parts and codes will be

[illegible]

preprinted. The only data entry necessary are parameters associated with each part or assembly. The format might be as follows:

Heat Exchanger Type A.F.T.

Part Name	Thickness (Inch)	Length (Feet)	Width (Feet)	Diameter (Inch)	Code 1	Code 2	Code 3
Shell Cover	X			X	2	1	
Shell Cover Skirt	X	X	X	X	1	1	
Shell Cover Flange	X			X			
Shell Barrel	X	X	X	X	1	1	
Shell Flange	X			X			
Channel Barrel	X	X	X	X	1	1	
Channel Flange	X			X			
Nozzle	X			X	6	1	1
Coupling	X			X	6	2	

3.9 Discussion and Conclusions

Comparing with the conventional methods of estimating, computer estimation technique is not only time saving but

has also the following advantages:

- (i) it is consistent; eliminating all guesswork
- (ii) standard developed through mathematical modelling is faster to establish since variables and time relationship are already identified, eliminating all unwanted insignificant details for the data collection process.
- (iii) time standards under mathematical formulas are not only in short form but also more accurate than the tabulated form. Moreover, it is not possible to present a multivariable relationship by tables or charts
- (iv) it is easy to revise, update and improve standard data under mathematical form by comparing to the actual time spent. Regression analysis computation for multivariables is easily performed since the form of the equation is already known

Theoretically, estimating by computer can be realized in all activities which can be measured quantitatively but, because of cost, it can be justified only in complex non-repetitive projects.

CHAPTER IV

A Dynamic Approach to Man-Power

Control and Scheduling

4.1 Formulation of the Problem

Estimating, cost control and scheduling are closely interrelated. Estimating provides basic data for setting up the production plan such as to determine man-power required and to prepare schedules for the project. Man-power and scheduling in turn will provide actual cost and time data for estimating. This inter-relationship could be visualized as a close circuit as shown in Fig 4.0.

The figure shows that the accuracy of any estimate requires optimum use of manpower. The optimum use of man-power in turn can be obtained only through optimum scheduling. There are two types of production plans to be considered:

- (1) single project with no resource constraints: Construction of a high-rise building is an example of this. Scheduling consists only of determining dates when various types of resources are required. These resources are theoretically supposed to be available when required. In this type of scheduling, the problem of man-power control is not crucial since all activities

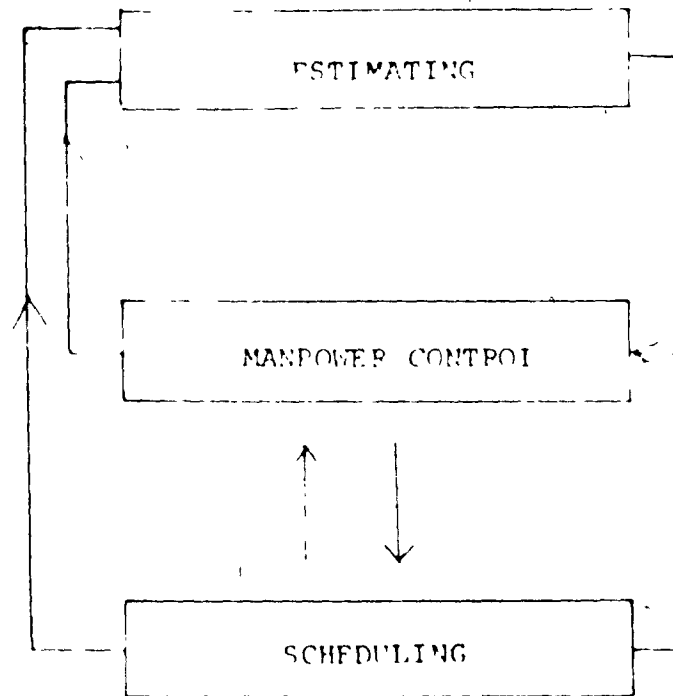


Fig. 4.0 Estimating, Manpower, Scheduling
Interrelationship.

can be preplanned in advance.

- (ii) Multiprojects with resource constraints:

This occurs frequently in the manufacturing industry where many projects are carried out at the same time using the same resources. The object of production planning is to optimize the use of resources and to meet delivery schedules of each individual project. This is a very complex problem since it involves many random variables such as:

- (1) award of orders.
- (2) material delivery.
- (3) machinery breakdown.
- (4) quality problems.
- (5) labour turn-over.
- (6) shop capacity, etc.

Due to all these causes, the production plan has a time-varying characteristic so that any analytical approach giving

only steady state solution either of deterministic or statistical nature becomes only an approximation. In this chapter, a dynamic computerized approach is proposed to optimize scheduling and cost. Before a detailed discussion is presented, an outline of steps involved is given below :

- (i) each project is defined by a certain quantity usually in terms of man-hours.
- (ii) progress of work for each project is assumed to be a certain function that is obtained through mathematical modelling.
- (iii) as a result of step (ii) , man-hr. level required for carrying all projects simultaneously is to be determined.
- (iv) the feasibility of the plan is to be established by comparing the man-hour level

required to the shop capacity.

- (v) After production has started, actual progress of work is recorded for each project. This is for comparing the original work schedule and from this a new schedule is generated. Consequently a new man-hour level for all projects is obtained. The forecast variance between the previous man-hour level and the new man-hour level is to be projected over the project time.

Such updating is to be made on a frequent basis. The object of management decision is to minimize the forecast variance or, in other words, to reduce the fluctuation of man-hour level forecast at each updating.

- (vi) All the above steps are to be computerized for mechanical updating. Details for each step are explained in the following section.

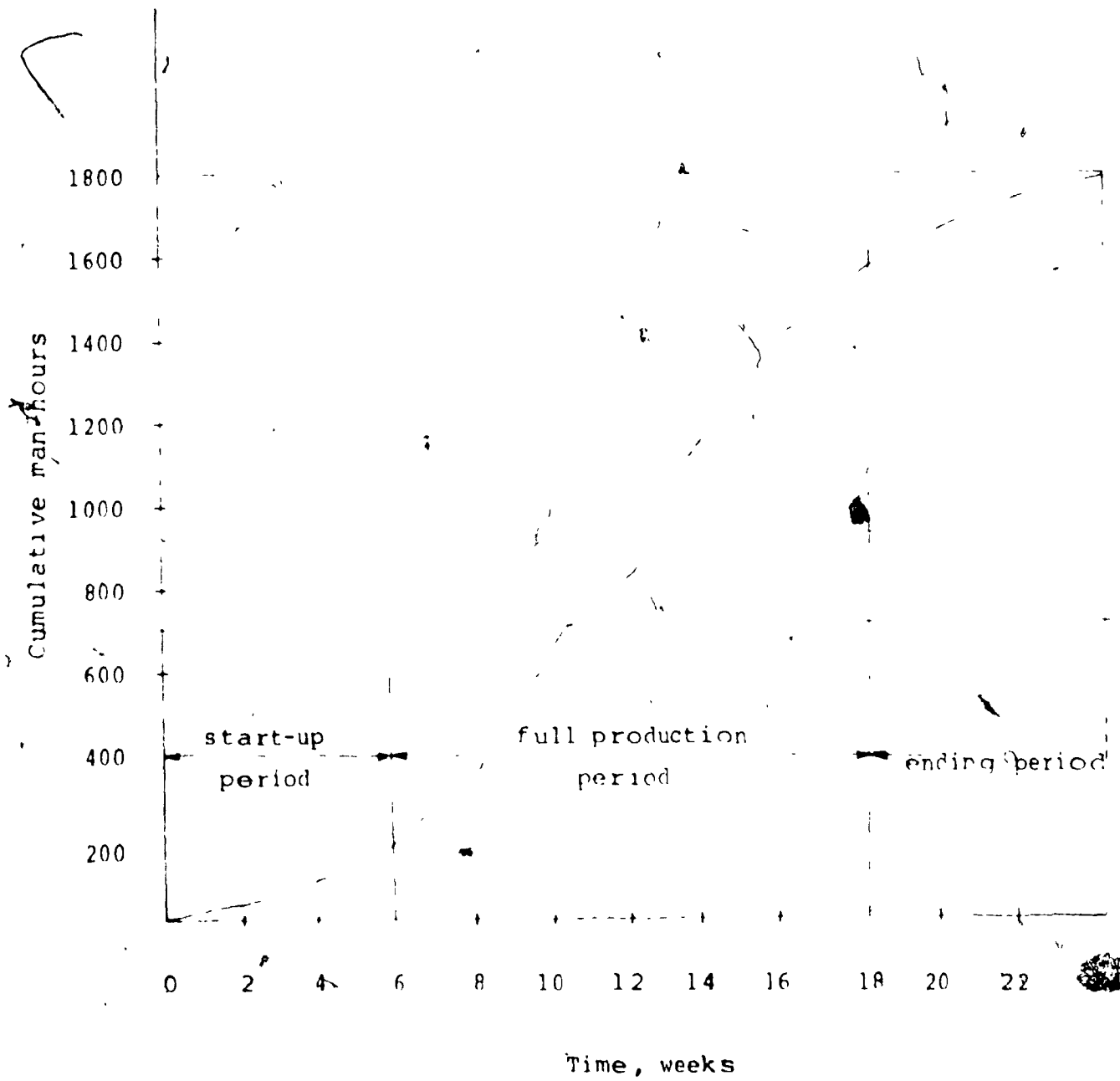


Fig. 4.1 Actual Cumulative Work Progress.

4.2 Mathematical Modelling for Work Schedules

If during the life of a project, the progress of work is plotted against time, a curve such as the one shown on Fig. 4.1 is usually obtained. This curve is shaped like an S and consists of three distinct portions, namely :

- (a) start-up period,
- (b) full manufacturing period,
- (c) ending period.

Based on this characteristic, a simplified model as shown in Fig. 4.2 is proposed to represent the progress schedule of a project. This curve contains the following information:

Q = is the total hr for the project

S = is the starting date of the project,
usually expressed as the day no. of the
manufacturing calendar.

F = is the completion date of the project.

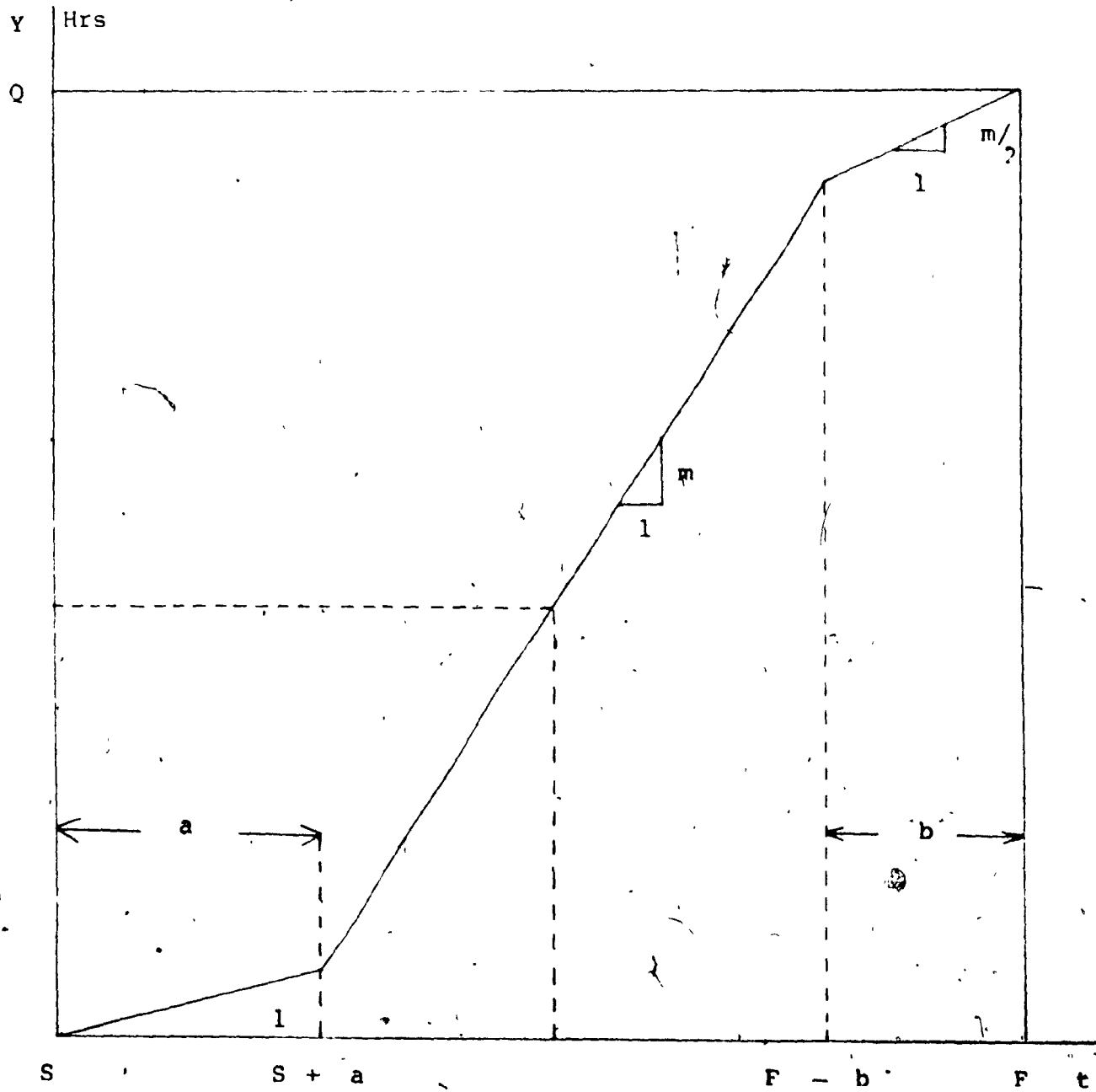


Fig. 4.2 Mathematical Modelling of Schedule Progress.

a is the start-up period, usually expressed as number of working days.

b is the ending period.

m is the slope of the full manufacturing period which is the only unknown variable.

The slope of the curve at the start-up and ending period is assumed to be $1/2 m$. It is required now to find the equation for this curve or precisely to find $y(t)$ for the following cases:

(i) $S \leq t < S+a,$

(ii) $S+a \leq t < F-b,$

(iii) $F-b \leq t \leq F.$

First of all, the slope m is to be determined from the following relation using the geometry of the curve.

$$a \frac{m}{2} + (F - b - S - a) m + b \frac{m}{2} = Q$$

$$m (2F - 2S - a - b) = 2Q$$

$$\text{or } m = \frac{2Q}{2(F - S) - a - b}$$

$$(i) \text{ for } S \leq t < S + a$$

$$y(t) = \frac{m}{2} (t - S) = \frac{Q(t - S)}{2(F - S) - a - b}$$

$$(ii) \text{ for } S + a \leq t < F - b$$

$$y(t) = \frac{m}{2} a + m(t - S - a)$$

$$= \frac{Q a}{2(F - S) - a - b} + \frac{2Q(t - S - a)}{2(F - S) - a - b}$$

$$= \frac{Q(2t - 2S - a)}{2(F - S) - a - b}$$

(iii) for $F - b \leq t < F$

$$y(t) = Q - \frac{m}{2} (F - t)$$

$$y(t) = Q - \frac{2 Q (F - t)}{2 (F - S) - a - b}$$

For the multiproject case, the progress schedule will be obtained by the above approach for each individual project. Each project will be determined by its own value of Q, S, a, b, F . Fig. 4.3 shows a family of curves representing the progress schedule of various projects.

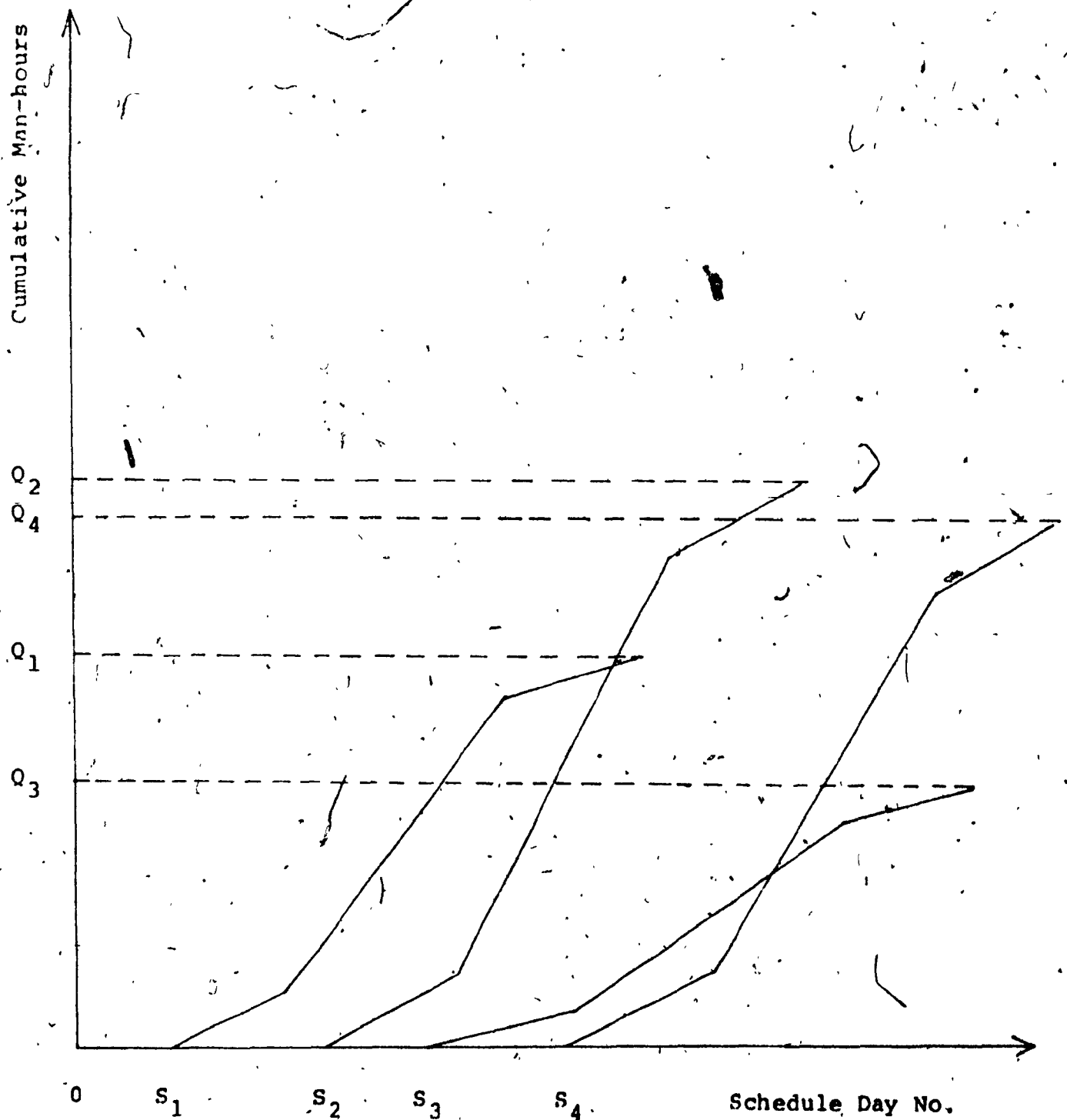


Fig. 4.3 Progress Schedule for the Multiproject Case.

4.3 Mathematical Modelling of the Overall Man-Hours Level for Multiproject Scheduling

Let Q_j , S_j , F_j , a_j , b_j be the parameters defined in Section 4.1 for project j , ($j = 1, n$).

Suppose $y_j(t)$ is the cumulative progress schedule for the project j at time t , then the total cumulative progress schedule $Y(t)$ for all projects is:

$$Y(t) = \sum_{j=1}^n y_j(t)$$

The total man-hours required to be completed during time interval $(t, t+h)$ is then:

$$Y(t+h) - Y(t) = \sum_{j=1}^n y_j(t+h) - \sum_{j=1}^n y_j(t)$$

Then the total man-hour level for all projects at time t is equal to the limit expressed by :

$$\lim_{h \rightarrow 0} \frac{Y(t+h) - Y(t)}{h}$$

or,

$$\lim_{h \rightarrow 0} \frac{Y(t+h) - Y(t)}{h} = Y'(t)$$

$$\begin{aligned} & \lim_{h \rightarrow 0} \frac{\sum_{j=1}^n y_j(t+h) - \sum_{j=1}^n y_j(t)}{h} \\ &= \sum_{j=1}^n y'_j(t) \end{aligned}$$

Plotting $Y'(t)$ against time, a curve shown in Fig. 4.4 is obtained. This curve shows how man-hours required is distributed over time to meet the schedules. The shaded area of this curve represents the work progress $W_0(i)$ required during interval (t_{i-1}, t_i) . Or

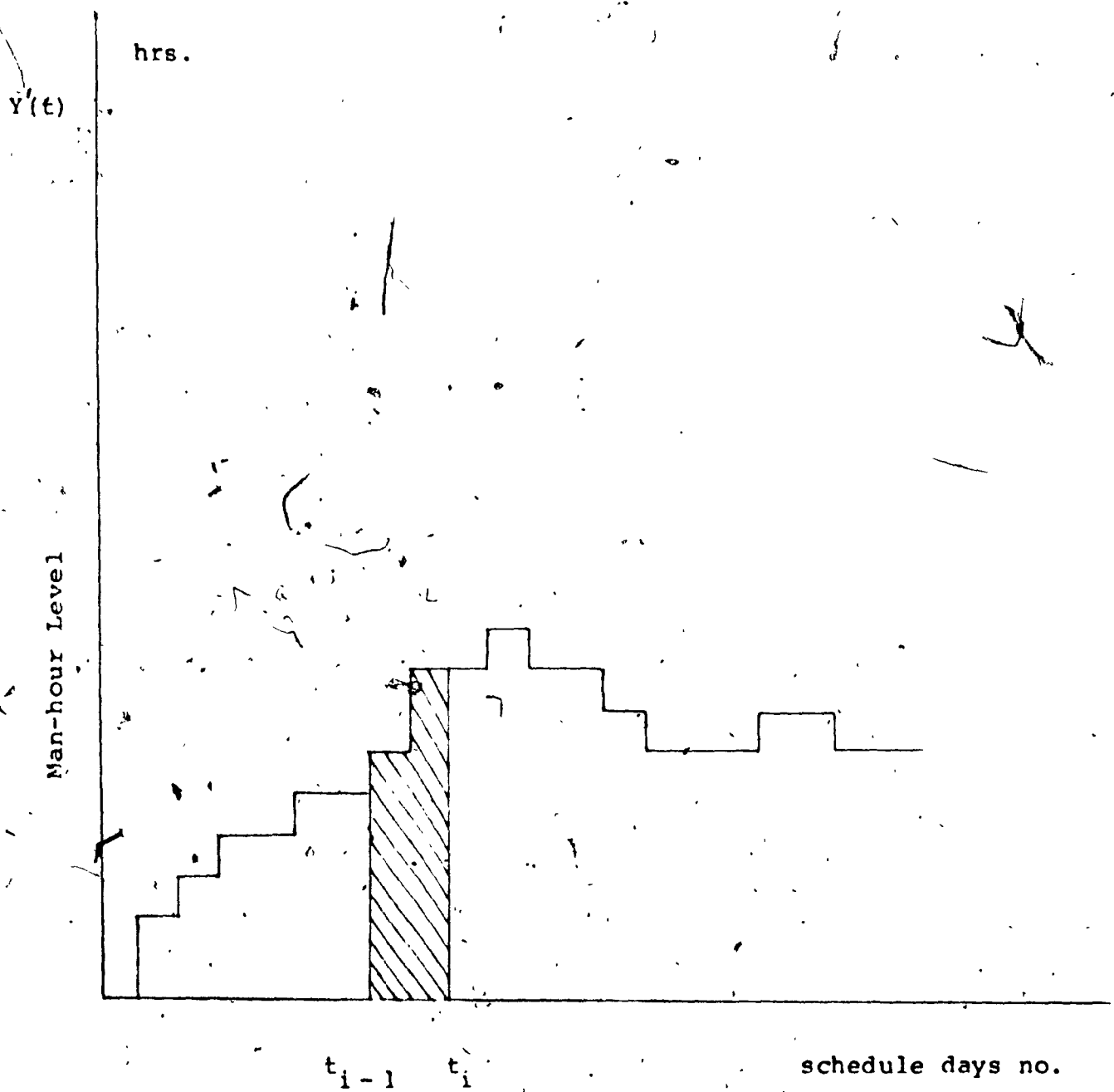


Fig. 4.4 Man-hour Level for All Projects.

$$W_0(i) = \int_{t_{i-1}}^{t_i} \sum_{j=1}^n y'_j(t) dt$$

$$= \int_{t_{i-1}}^{t_i} Y'(t) dt$$

$$= Y(t_i) - Y(t_{i-1})$$

The feasibility of the plan can be determined by comparing the man-hour level required to the maximum production capacity.

4.4 Updating of the Schedule

4.4.1 Actual Completion VS Forecast Completion

During the progress of each project, the actual completion is recorded and its cumulative value $x_j(t)$ is plotted on the same graph Fig. 4.5 showing the progress schedule $y_j(t)$. The following conclusion can be then deduced:

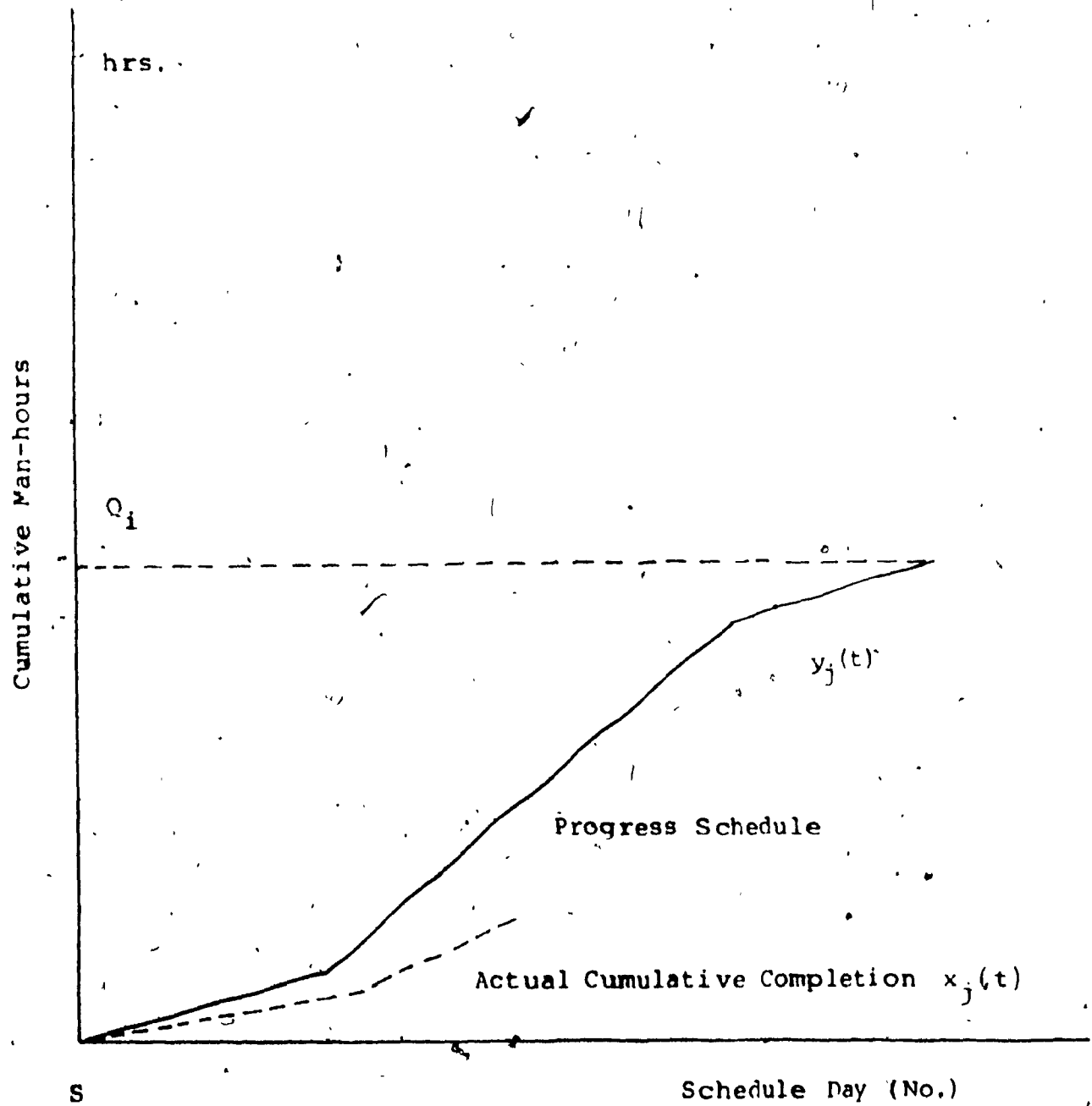


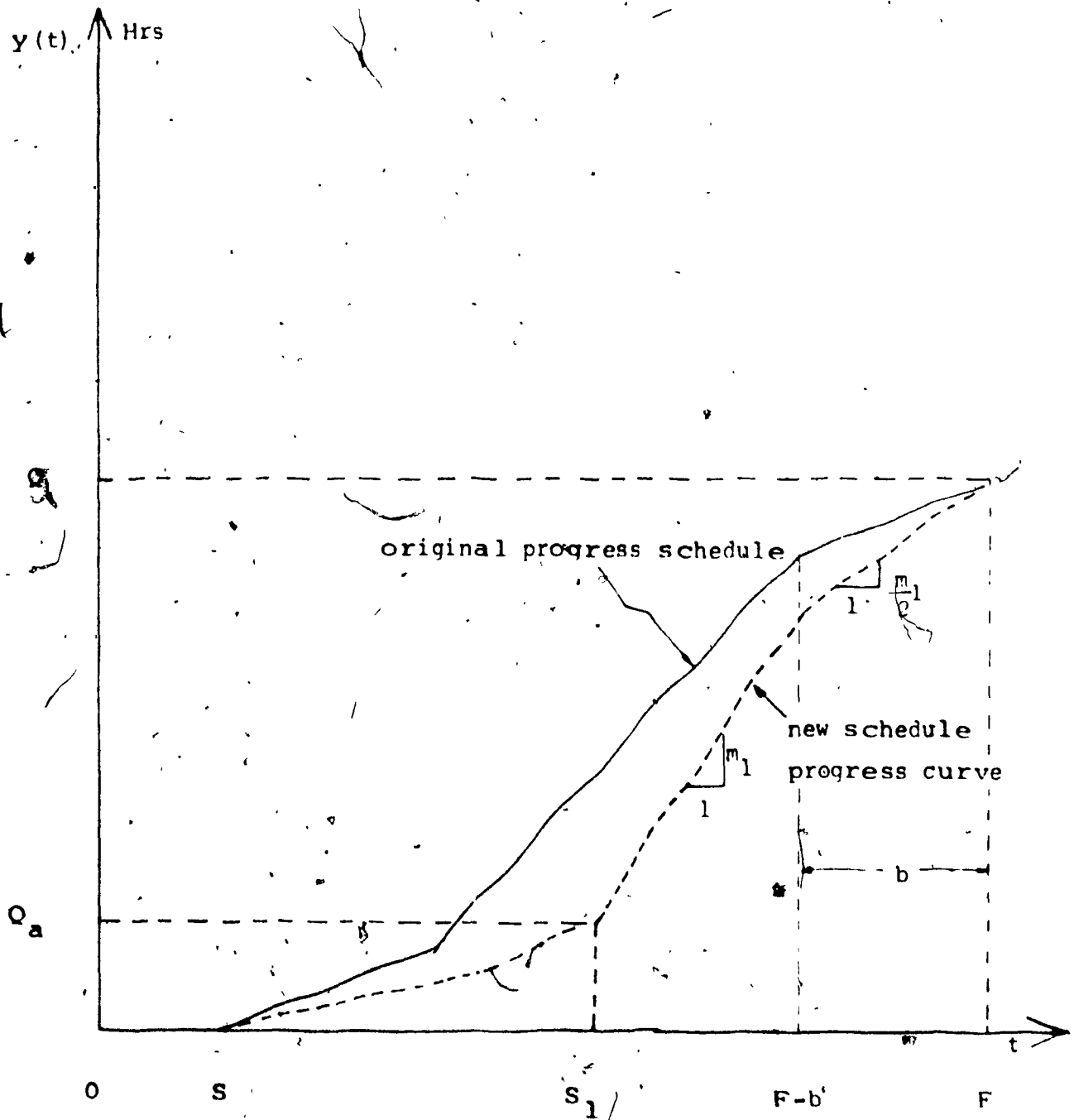
Fig. 4.5 Actual VS Scheduled Completion.

- (i) if $x_j(t) > y_j(t)$: then project j
is ahead of sche-
dule.
- (ii) if $x_j(t) < y_j(t)$: project j is be-
hind of schedule.
- (iii) if $x_j(t) = y_j(t)$: project j is on
schedule.

Fig. 4.5 shows the situation where the actual completion $x_j(t)$ is behind schedule $y_j(t)$.

4.4.2 Schedule Updating

Since there is a variance between the actual completion and the scheduled completion, to maintain the delivery date, the schedule must be revised showing the new man-hour requirement. The updated schedule curve together with the original schedule curve is shown on Fig. 4.6 in which S_1 is defined as the status date, O_a as the cumulative actual completion. To find the equation for the update schedule, it is assumed that during interval $(S_1, F-b)$, the production is at constant completion rate m_1 and during the ending interval $(F-b, F)$, the completion rate is equal to $1/2 m_1$. The slope m_1 is then calculated from the following relation:



S_1 : updating date Q_a = actual completion

Fig. 4.6 Update Schedule.

$$m_1 (F - b - S_1) + \frac{m_1 b}{2} = Q - Q_a$$

$$\frac{m_1}{2} (2F - b - 2S_1) = Q - Q_a$$

$$\text{then } m_1 = \frac{2(Q - Q_a)}{2F - b - 2S_1}$$

the updating equation for $y(t)$ is then:

$$(i) \quad S_1 \leq t < F - b$$

$$y(t) = m_1 (t - S_1) = \frac{2(Q - Q_a)(t - S_1)}{2F - b - 2S_1}$$

$$(ii) \quad F - b \leq t < F$$

$$y(t) = Q - \frac{m_1}{2} (F - t) = Q - \frac{(Q - Q_a)(F - t)}{2F - b - 2S_1}$$

4.4.3 Production Status for the Multiproject Case

The overall man-hour level is also required to be updated after production has already started. The update must also be made on a frequent basis, preferably at the beginning of each period. A period could be a month, a week, etc. As by Section 4.3, $W_0(i)$ is defined as the work progress schedule for all projects for period i with i varying from 1 to m . After the first period has elapsed, the first update is made, and similarly $W_1(i)$ is defined as the first updated work progress schedule for period i . For the first update, i varies from 2 to m since the first period ($i = 1$) has elapsed. Similarly for the general case, $W_p(i)$ is defined as the p^{th} updated work progress schedule for period i with i varying from p to m .

In the same way, the following nomenclature is used for subsequent developments:

$y_{j,p}(t)$ = the p^{th} update for the cumulative work schedule of project j , j varying from 1 to n .

$Y_p(t)$ = the p^{th} update for the total cumulative work schedule for all projects.

Period i is time interval defined by the starting date t_{i-1} and ending date t_i of the schedule calendar.

$y_j^p(i)$ = the p^{th} update for work schedule of project j for period i , i varies from p to m :

$$y_j^p(i) = y_j(t_i) - y_j^p(t_i - 1)$$

$w_p(i)$ = the p^{th} update for work schedule of all projects for period i :

$$\begin{aligned} w_p(i) &= y_p(t_i) - y_p(t_i - 1) \\ &= \sum_{j=1}^n y_j^p(t_i) - \sum_{j=1}^n y_j^p(t_i - 1) \end{aligned}$$

From the above nomenclature, the following equations may be derived:

(i) backlog of work for project j at the p^{th} update, $\sum_{i=p}^m w_j^p(i)$:

$$\begin{aligned} \sum_{i=p}^m w_j^p(i) &= \sum_{i=p}^m y_j^p(t_i) - y_j^p(t_i - 1) \\ &= y_j^p(t_m) - y_j^p(t_p - 1) \end{aligned}$$

where $y_j^p(t_m) =$ total hrs for project j ; Q_j .

$y_j^p(t_p - 1) =$ actual cumulative completion of project j at the p^{th} update.

(ii) backlog of work for all projects at the p^{th} update, $\sum_{i=p}^m w_p(i)$:

$$\sum_{i=p}^m w_p(i) = \sum_{i=p}^m [y_p(t_i) - y_p(t_i - 1)]$$

$$= y_p(t_m) - y_p(t_p - 1)$$

$$= \sum_{j=1}^n y_j^p(t_m) - \sum_{j=1}^n y_j^p(t_p - 1)$$

(iii) forecast variance for work completion of project j for period i at the p^{th} update,

$$w_j^p(i) = w^{p-1}_j(i)$$

$$\begin{aligned}
 w_j^p(i) - w_j^{p-1}(i) &= y_j^p(t_i) - y_j^p(t_{i-1}) - \\
 &\quad y_j^{p-1}(t_i) + y_j^{p-1}(t_{i-1}) \\
 &= [y_j^p(t_i) - y_j^{p-1}(t_i)] - \\
 &\quad - [y_j^p(t_{i-1}) - y_j^{p-1}(t_{i-1})]
 \end{aligned}$$

(iv) Actual time completion of project j for period $i = p - 1$ at the p^{th} update,

$$\sum_{i=p-1}^m w_j^{p-1}(i) = \sum_{i=p}^m w_j^p(i)$$

$$\sum_{i=p-1}^m w_j^{p-1}(i) - \sum_{i=p}^m w_j^p(i) = w_j^{p-1}(p-1) +$$

$$\left[\sum_{i=p}^m w_j^{p-1}(i) - \right.$$

$$\left. \sum_{i=p}^m w_j^p(i) \right]$$

w_j^{p-1} (p-1) is the forecast completion of project j at the (p-1)th forecast, therefore, the status of the actual completion as compared to the forecast completion depends on the sign of the expression

$$\sum_{i=p}^m w_j^{p-1}(i) - \sum_{i=p}^m w_j^p(i)$$

$$(a) \quad \sum_{i=p}^m w_j^{p-1}(i) - \sum_{i=p}^m w_j^p(i) > 0,$$

the work is ahead of schedule.

$$(b) \quad \sum_{i=p}^m w_j^{p-1}(i) - \sum_{i=p}^m w_j^p(i) < 0,$$

work is behind schedule.

(v) Actual completion of all projects for period $i = p-1$ at the pth update,

$$\sum_{i=p-1}^m w_{p-1}(i) - \sum_{i=p}^m w_p(i)$$

$$\sum_{i=p-1}^m w_{p-1}(i) - \sum_{i=p}^m w_p(i) = w_{p-1}(p-1) +$$

$$\sum_{i=p}^m [w_{p-1}(i) - w_p(i)]$$

where $w_{p-1}(p-1)$ is the forecast completion of all projects for period $i = p-1$, therefore, if

$$(a) \quad \sum_{i=p}^m [w_{p-1}(i) - w_p(i)] > 0,$$

work is ahead of schedule.

$$(b) \quad \sum_{i=p}^m [w_{p-1}(i) - w_p(i)] < 0,$$

work is behind schedule.

4.4.4 Project Monitoring and Control

The objects of project monitoring and control are:

- (i) to meet the schedule of each individual project,
- (ii) to minimize the cost.

4.4.4.1 Meeting Schedule For Each Individual Project

Here the problem is to minimize the expression

$$\left| \sum_{i=p}^m w_j^{p-1}(i) - w_j^p(i) \right|$$

for $j = 1, n$ or it is required to minimize:

$$\sum_{j=1}^n \left| \sum_{i=p}^m [w_j^{p-1}(i) - w_j^p(i)] \right|$$

or,

$$\sum_{j=1}^n \sum_{i=p}^m |w_j^{p-1}(i) - w_j^p(i)| \geq$$

$$\left| \sum_{j=1}^n \sum_{i=p}^m [w_j^{p-1}(i) - w_j^p(i)] \right|$$

$$\geq \left| \sum_{i=p}^m \sum_{j=1}^n [w_j^{p-1}(i) - w_j^p(i)] \right|$$

with

$$\sum_{j=1}^n [w_j^{p-1}(i) - w_j^p(i)]$$

$$= w_p^{p-1}(i) - w_p^p(i)$$

then
$$\sum_{j=1}^n \left| \sum_{i=p}^m \left[w_j^{p-1}(i) - w_j^p(i) \right] \right| \geq$$

$$\left| \sum_{i=p}^m \left[w_p^{p-1}(i) - w_p^p(i) \right] \right|$$

This proves that in multiproject scheduling, to obtain the first objective, it is required only to meet the overall schedule rather than trying to meet the schedule of each individual project. This can be obtained by keeping

$$\left| \sum_{i=p}^m \left[w_p^{p-1}(i) - w_p^p(i) \right] \right| \text{ as small as possible.}$$

Let $Z(p) = \sum_{i=p}^m \left[w_p^{p-1}(i) - w_p^p(i) \right]$ and plotting

it as function of p , the following cases may be obtained.

Case 1: This is represented by Fig. 4.7.

$Z(p)$ is a decreasing function showing that the overall completion is always behind schedule. It suggests that one or many of the following problems exist:

- (a) low labour performance.
- (b) lack of manpower.
- (c) lack of shop capacity.
- (d) unrealistic scheduling.

Case 2: This is represented by Fig. 4.8:

$Z(p)$ is an increasing function showing that the job is always ahead of schedule. It suggests that one or more of the following problems exist

- (a) excess of manpower.
- (b) loose standard data.

Case 3: This is represented by Fig. 4.9.

$Z(p)$ fluctuates to a great extent across the p axis. It suggests the existence of one or many of the following problems:

- (a) inconsistent standard data.
- (b) material shortage.
- (c) unrealistic scheduling.

Case 4: This is represented by Fig. 4.10:

$Z(p)$ fluctuates in a small narrow range, suggesting that the overall completion is satisfactory as compared to the schedule.

Equation
$$Z(p) = \sum_{i=p}^m [w_{p-1}(i) - w_p(i)]$$

Forecast Variance $Z(p)$, Hours

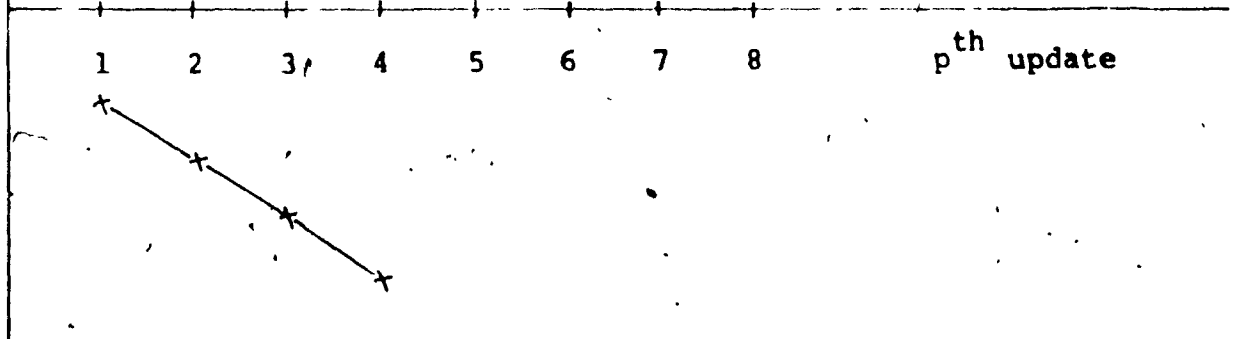


Fig. 4.7 Case 1 For The Forecast Variance

Equation:

$$z(p) = \sum_{i=p}^{m_i} [w_{p-1}(i) - w_p(i)]$$

Forecast Variance $z(p)$, Hours

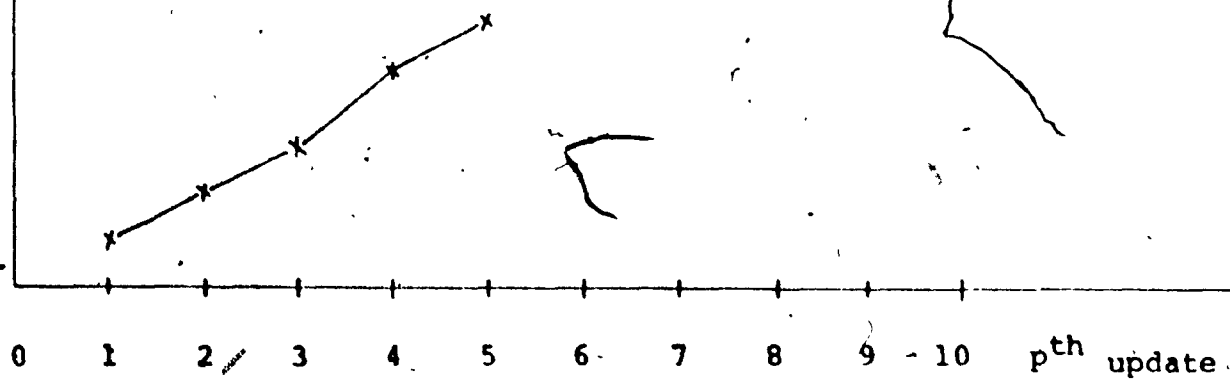


Fig. 4.8 Case 2 Of The Forecast Variance.

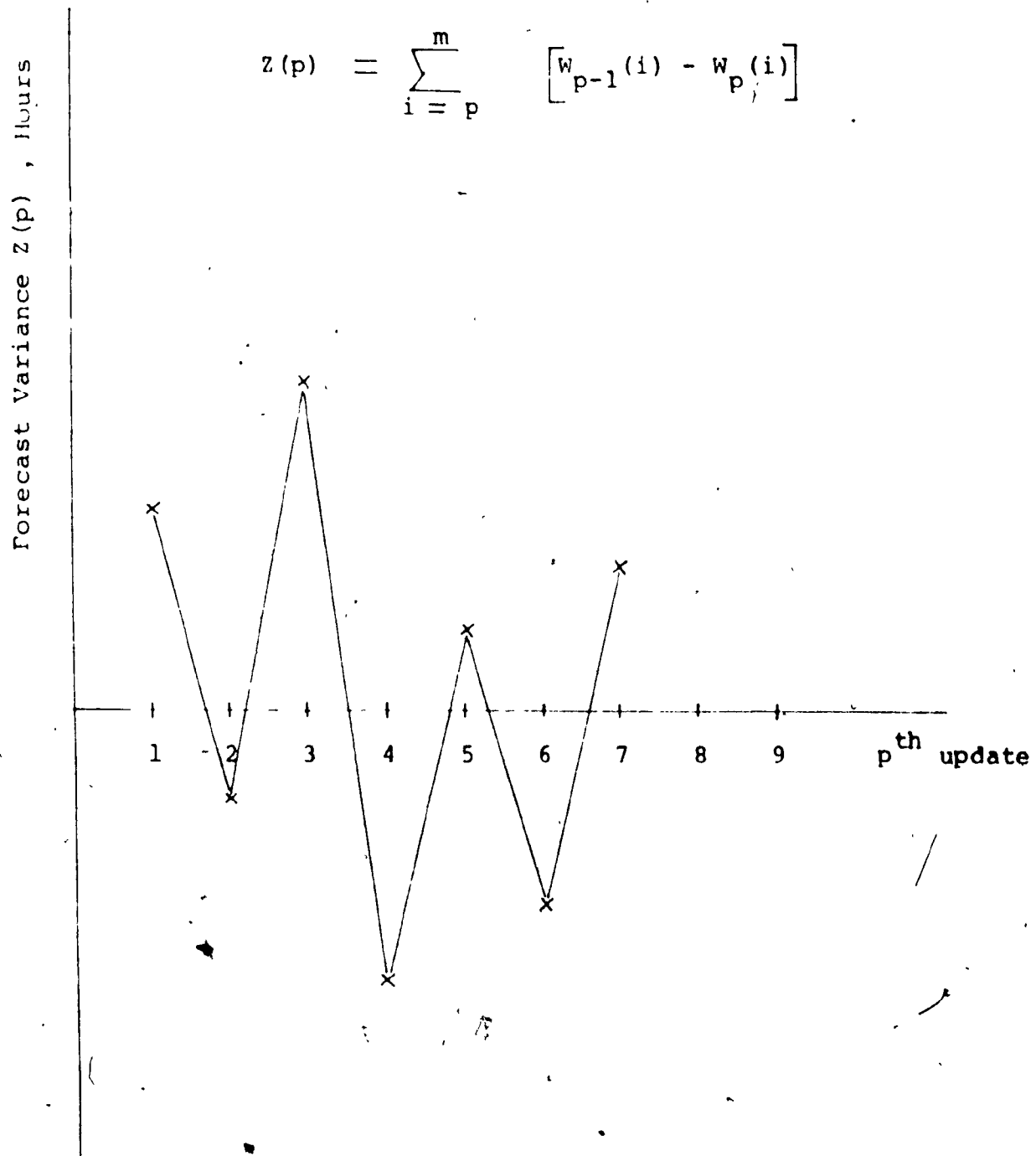


Fig. 4.9 Case 3 Of The Forecast Variance

$$z(p) = \sum_{i=p}^m [w_{p-1}(i) - w_p(i)]$$

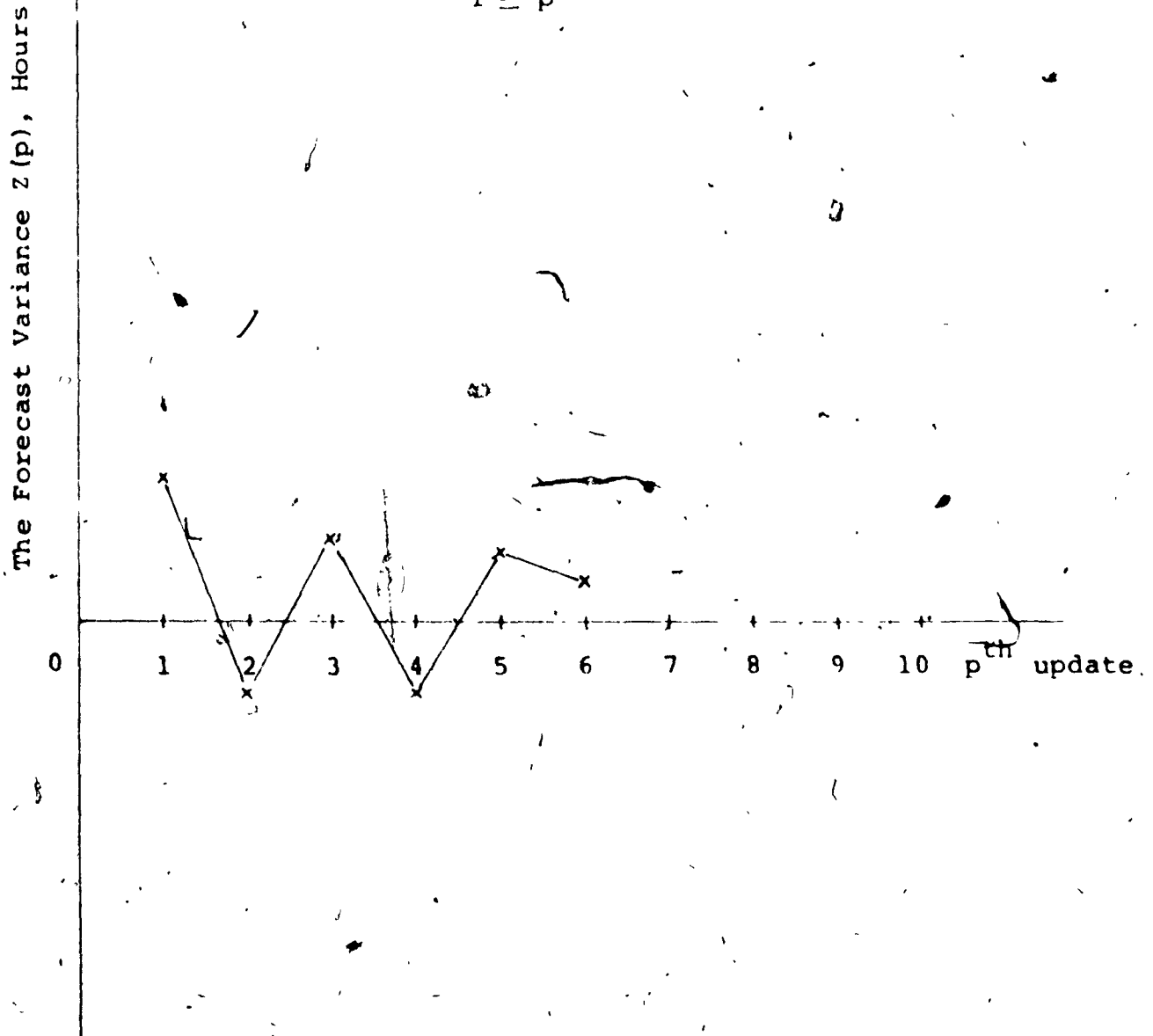


Figure 4.10 Case 4 of Forecast Variance

4.4.4.2 Minimization of Labour Cost

One of the criteria for labour cost minimization is that the production is under control. In other words, the variances of the work forecast for every production period are to be minimized.

Let $\bar{w}_p(i)$ = Mean value of work forecast
 $w_j(i)$; $j = 1, p$

$$\text{Then } \bar{w}_p(i) = \frac{1}{p} \sum_{j=1}^p w_j(i)$$

Let $v_p(i)$ = Variance of work forecast
 $w_j(i)$, $j = 1, p$

$$v_p(i) = \frac{1}{p} \sum_{j=1}^p \left| w_j(i) - \bar{w}_p(i) \right|^2$$

Since $v_p(i) > 0$

$$\sum_{i=1}^p \min v_p(i) = \min. \sum_{i=1}^p v_p(i)$$

This shows that to achieve minimization of labour cost, it is required to minimize the sum of forecast variance for every production period.

Suppose $V_a(p) = \sum_{i=1}^m v_p(i)$ and by plotting

$V_a(p)$ as a function of p , one of the following cases may be obtained:

Case 1: This is shown by Fig. 4.11. $V_a(p)$ is an increasing function showing that the production plan is in the unsteady state. It is a clear indication of high labour cost.

Case 2: This is represented by Fig. 4.12. $V_a(p)$ is a decreasing function which is an ideal indication of labour cost as well as schedule status.

Case 3: This is represented by Fig. 4.13. $V_a(p)$ fluctuates but follows a decreasing trend showing that production improves each time the plan is updated. It is a good indication that the labour cost is under control.

$$v_a(p) = \sum_{i=1}^m v_p(i)$$

Forecast Variance $V_a(p)$, Hours

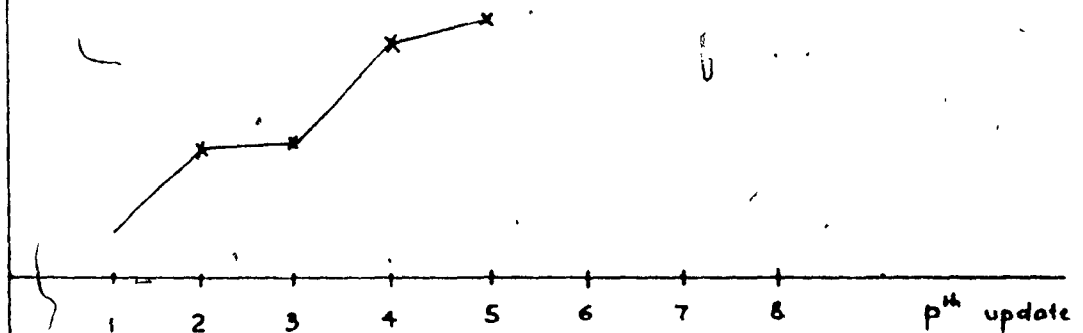


Fig. 4.11 Case 1 of Sum of Forecast Variance For All Production Periods

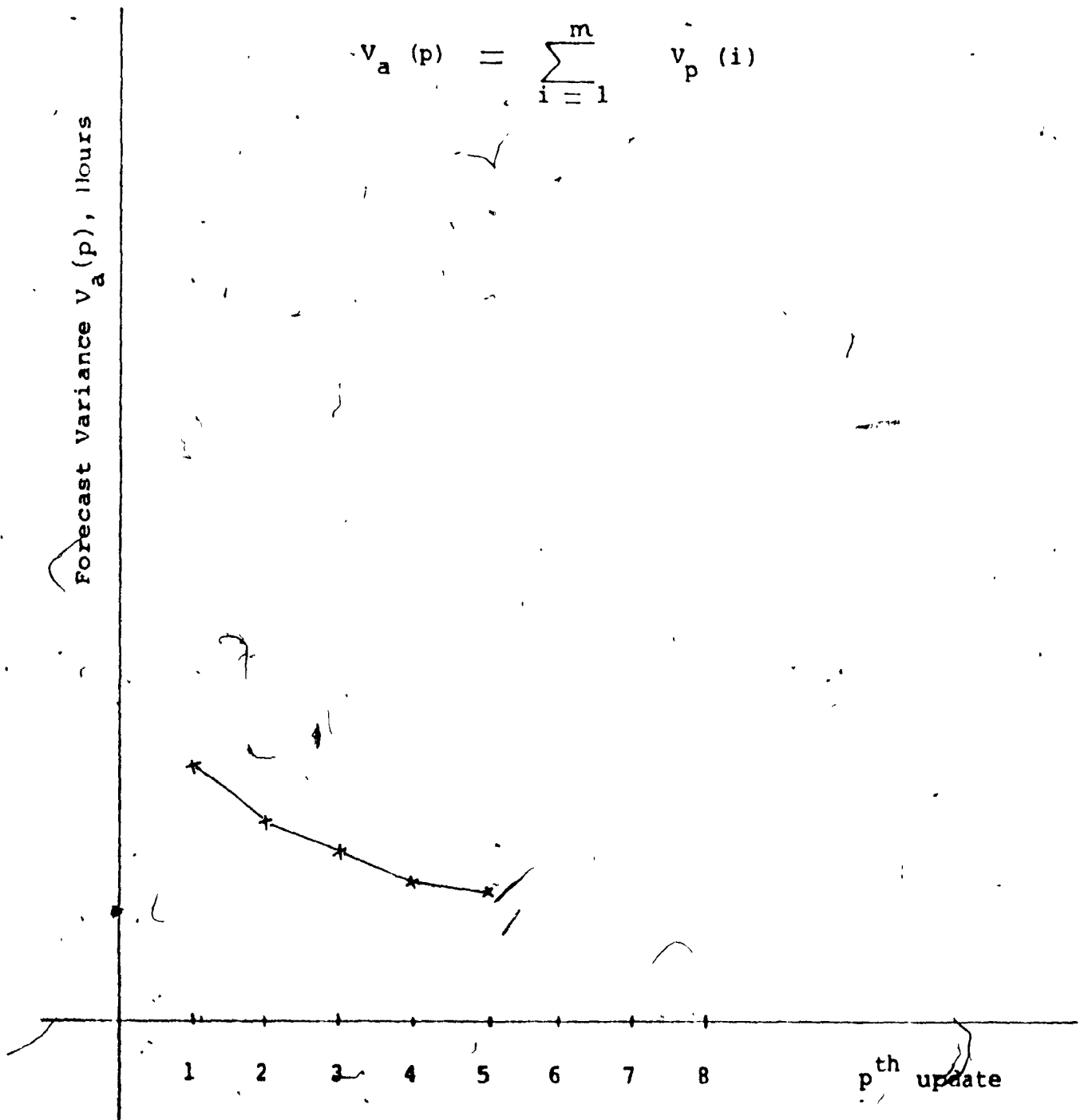


Fig. 4.12 Case 2 For Sum of Forecast Variance of All Periods.

Forecast Variance: $V_a(p)$, Hours

$$V_a(p) = \sum_{i=1}^m V_p(i)$$

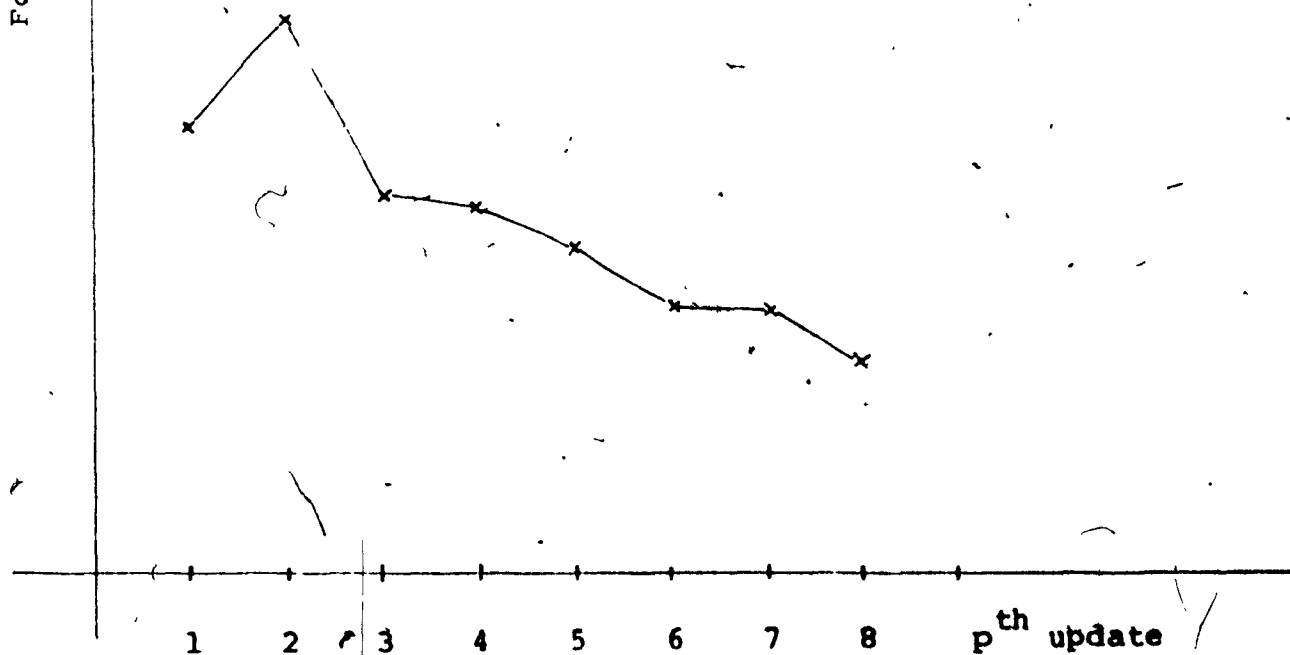


Fig. 4.13 Case 3 For The Sum Of Forecast Variance

4.5 Computer Program for Labour Forecast and Updating

The listing of the program based on the new approach presented in previous sections is given in the appendix.

The input data for the program are:

- (a) project name, total hours, starting day, ending day, and completion hours.
- (b) ending day for each production period.
- (c) the update no.
- (d) previous forecast.

A sample of the print-out is shown on page 121.

LABOUR FORECAST FOR MULTIPROJECTS AND DEFCH

ORDER NO.	TOTAL HRS.	HRS COMPLE.	HA REC. HRS.	JUL 74	JUL 74	AUG 74	SEP 74	OCT 74	NOV 74	DEC 74	JAN 75
PROJ. 1	300	151	149	0.000000	42.7	36.6	52.3	10.5	0.000000	0.000000	0.000000
PROJ. 2	4900	4805	235	0.000000	215.0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 3	4800	0	4800	231.5	657.1	484.2	651.7	651.7	760.9	726.1	380.5
PROJ. 4	5200	5200	1756	0.000000	1756.0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 5	5000	100	4900	0.000000	1471.6	1415.9	2022.7	2022.7	1517.0	0.000000	0.000000
PROJ. 6	1450	150	1300	0.000000	221.8	164.9	235.6	235.6	200.2	0.000000	0.000000
PROJ. 7	600	300	300	0.000000	16.6	71.2	101.7	101.5	0.000000	0.000000	0.000000
PROJ. 8	600	480	120	0.000000	42.1	20.9	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 9	350	60	290	0.000000	72.4	58.5	63.5	62.6	0.000000	0.000000	0.000000
PROJ. 11	500	0	500	15.2	113.1	61.3	112.0	87.3	0.000000	0.000000	0.000000
PROJ. 10	150	20	130	0.000000	12.0	8.8	12.6	12.6	11.9	13.2	6.7
PROJ. 13	1700	710	990	0.000000	414.9	308.6	242.5	0.000000	0.000000	0.000000	0.000000
PROJ. 14	1700	211	1489	0.000000	103.4	74.8	105.7	105.7	116.3	111.0	100.4
PROJ. 15	2019	2619	400	0.000000	330.4	67.6	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 16	2876	1302	1574	0.000000	323.8	238.6	340.3	340.3	289.8	0.000000	0.000000
PROJ. 17	2700	2300	400	0.000000	195.0	144.4	51.2	0.000000	0.000000	0.000000	0.000000
PROJ. 18	1000	0	1000	31.0	452.4	166.7	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 19	1200	1000	200	0.000000	200.0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 20	3200	544	2656	0.000000	692.6	166.2	525.1	525.1	574.5	457.8	0.000000
PROJ. 21	12400	0	12500	0.000000	0.000000	641.3	1861.5	1849.2	2056.5	1963.0	1776.1
PROJ. 22	5200	0	5200	0.000000	0.000000	0.000000	0.000000	0.000000	750.4	492.7	618.2
PROJ. 23	300	0	300	0.000000	0.000000	0.000000	0.000000	111.5	178.4	8.1	0.000000
PROJ. 24	3300	0	3300	0.000000	0.000000	0.000000	0.000000	644.2	604.1	666.3	602.4
PROJ. 25	2500	0	2500	0.000000	0.000000	0.000000	0.000000	312.2	500.0	477.1	431.4
PROJ. 26	600	0	600	0.000000	162.5	175.0	250.0	12.5	0.000000	0.000000	0.000000
PROJ. 27	16000	0	16000	0.000000	0.000000	0.000000	0.000000	1555.6	2444.4	2333.1	2111.1
PROJ. 28	30000	0	30000	0.000000	0.000000	0.000000	0.000000	0.000000	63000.0	2255.4	2704.2
PROJ. 29	150	0	150	0.000000	0.000000	0.000000	0.000000	0.000000	52.2	68.5	7.1
PROJ. 30	11000	0	11000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 31	3200	0	3200	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 32	3200	0	3200	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 33	1200	0	1200	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 34	3200	0	3200	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 35	3200	0	3200	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
PROJ. 36	1200	0	1200	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
TOTAL	241.7	1077.4	4730.6	670.1	2441.6	10162.5	9813.5	5744.4			
DEFCH	115.2	4566.4	4832.6	2555.5	10347.9	9806.2	9149.6	1014.1			
GRAND TOTAL	356.9	15343.8	9563.2	9255.6	14789.5	19968.7	20963.1	15858.5			

DEFCHINGS 445

0

0.0

TOTAL COMPLETION WORK-TO-DO 15343.8

CHAPTER V

SUMMARY AND CONCLUSIONS

In this dissertation, a new approach for computerized cost estimation is presented. The main ideas of this approach can be summarized as follows:

- (i) Mathematical modelling of estimating standard data.
- (ii) Classifying components into families and groups in such a way so as to minimize the number of time formulas.
- (iii) Coding components on the basis of family and group and writing the computer program accordingly.
- (iv) Standardizing input formats for speeding up data preparation.
- (v) Comparing estimates by computer of actual time spent to improve the reliability of time formulas.

The proposed method has a number of advantages over the conventional methods, the most important of which are:

- (i) Eliminating all guesswork.

- (ii) Consistency in the estimating process.
- (iii) More reliable standard data since it can be subjected to contiguous revisions and updatings.
- (iv) Reducing estimate costs.
- (v) Instantaneous estimating results.

To show an application of the technique developed, a case study for computerized estimating of labour time in the production of heat exchangers is presented in details. The actual method and the computer program for this are presented and the listing is given in Appendix I.

Further in Chapter IV, a new dynamic approach for manpower control and scheduling is explained. This chapter together with Chapter II form a new integrated approach for manufacturing control. The main ideas of Chapter IV can be summarized as follows:

- (i) Mathematical modelling of work progress of a project as a function of its man-hours, its starting day and its completion day of the schedule calendar.
- (ii) As a result of the mathematical modelling for each individual project, the manpower level required to execute all projects

together is to be determined for each manufacturing period.

- (iii) After a manufacturing period has elapsed, the actual completion hour for each project is recorded and is compared to the forecast completion. A new manhour forecast is generated for each project, and a new manhour level for all projects required for each manufacturing period is to be determined. Updating is required at the end of each manufacturing period.
- (iv) The overall work progress status defined as the difference between the actual completion and the forecast completion is plotted against the update number. Depending on the trend of the curve, decisions are made to minimize the forecast variance and at the same time to minimize the labour cost.
- (v) A computer program for implementing the above steps is developed and given in Appendix II. A sample of the computer print-out is also given.

The new approach has many advantages, the most important of which are :

- (i) It is a dynamic approach adaptable to the time varying characteristic of the production plan.
- (ii) Coordination and optimization of resources required for many projects can be realized through the frequent up-datings of the overall plan.

These two new approaches presented above can be integrated into a more general computerized network which includes the C.P.M. network for each individual project. The main idea of the general computerized network is shown in Fig. 5.1.

The above approach is not applicable to a mass-production type of industry. Where production is almost at a steady state, the analytical techniques particularly useful for optimization for this type of industry are linear programming and queuing theory.

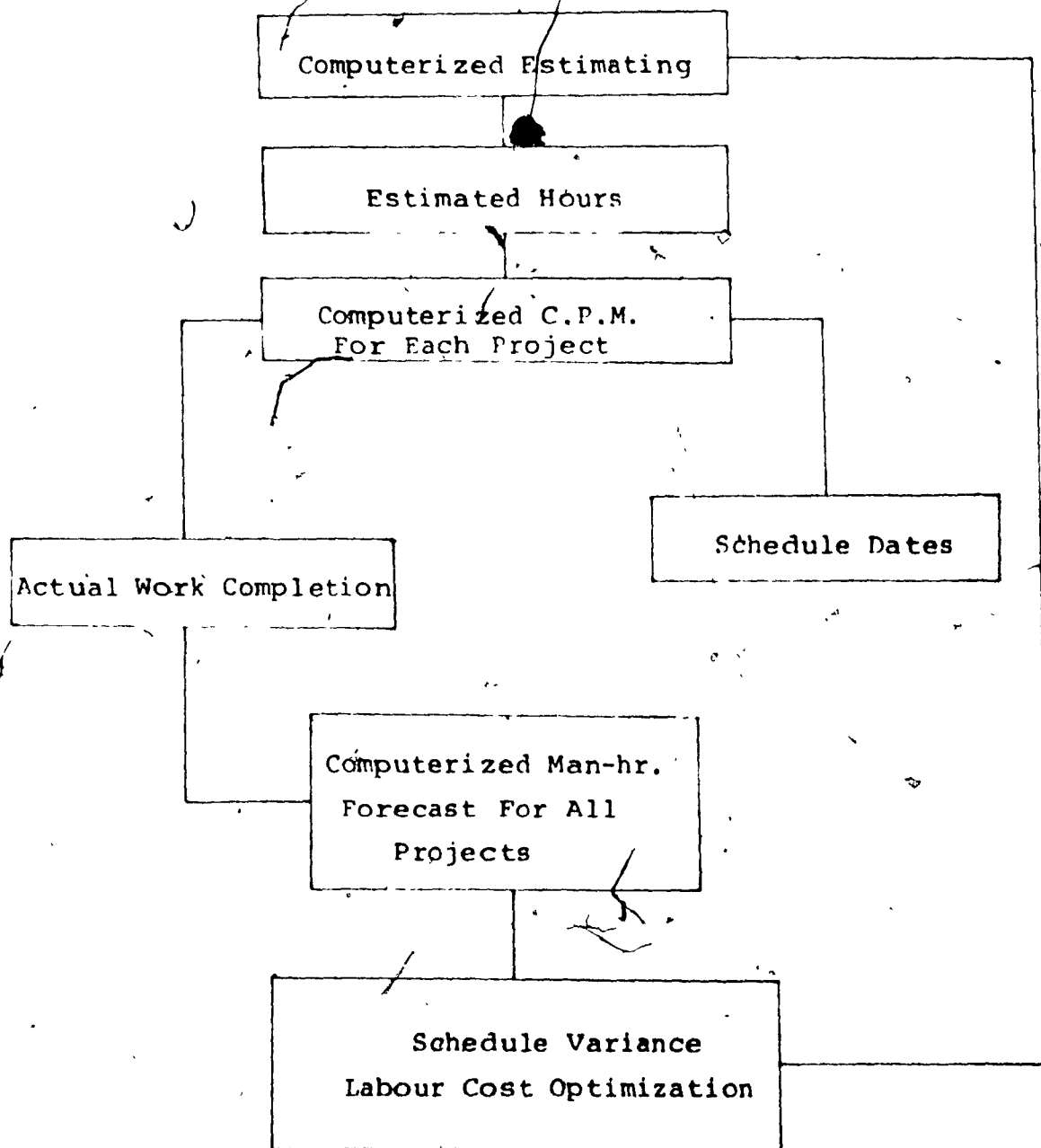


Fig. 5.1 A General Computer Network for Manufacturing Control.

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Appendix I

Computer Program For Estimating

Labour Time For Manufacturing

Heat Exchangers

COE 1000 11. 10.11-12. 11.11. 1971. 1971. 14.

[illegible]

CODE 2 (22,5) + CODE 3 (22,5) + CODE 4 (22,5)

NR 40 10166(1) 0.1

U. C. 4420 (N. O. L.)

1 2 1 (A) = 0

CCUDE 44(1), NY(1), PI(1)

LEL (K)

NAME (PRINTED)
LIBRARY

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CSC 0000 P.T. 03.0-4246 OF 1 13/10/23. 1

```

T1(K,L)=1111(J)
LL(K,L)=1111(J)
W(K,L)=W1(J)
C(K,L)=C1(J)
D1(K,L)=D11(J)
J2(K,L)=J22(J)
I(K,L)=I1(J)
N1(K,L)=N11(J)
I2(K,L)=I22(J)
K3(K,L)=K33(J)
CODE1(K,L)=CODE11(J)
CODE2(K,L)=CODE22(J)
CODE3(K,L)=CODE33(J)
CODE4(K,L)=CODE44(J)
P(K,L)=P1(J)
90 DO 304 K=1,22
DO 304 L=1,5
AA(K,L)=0.
AB(K,L)=0.
AC(K,L)=0.
AD(K,L)=0.
304 AA(K,L)=0.
DO 305 K=1,5
DO 305 L=1,5
AF(K,L)=0.
305 AF(K,L)=0.
DO 306 K=1,12
DO 306 L=1,5
AJ(K,L)=0.
AK(K,L)=0.
AL(K,L)=0.
AM(K,L)=0.
AO(K,L)=0.
306 AS(K,L)=0.
DO 307 K=1,16
DO 307 L=1,5
AH(K,L)=0.
307 AH(K,L)=0.
DO 308 K=1,22
DO 308 L=1,15
308 AA(K,L)=0.
LA=L1(J)
IF(LA=J)192,193,192
192 DO 100 L=1,LA
AA(I,L)=(T(I,L)*(1.20*LL(I,L)+.50*W(I,L))+.17*C(I,L)+
MF(CODE2(I,L),E0,2)GO TO 14
AB(I,L)=(LL(I,L)+W(I,L))*(1.22*J1(J)+.021*.54*LL(I,L)+
C30*T(I,L)*.02*LL(I,L)/D(I,L)+2.4)*I1(J)
AC(I,L)=(1.21*I1(J)+.315*T(I,L)*.02*LL(I,L)+.17*W(I,L)
GO TO 100
14 AB(I,L)=(LL(I,L)+W(I,L))*(1.22*J1(J)+.021*.54*LL(I,L)+
AD(I,L)=(1.50*.50*(LL(I,L)+W(I,L))+I1(J)*.02*.54*LL(I,L)
100 CONTINUE

```

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COMPUT

EST1

-132-

13/10/23. 14

```

143 LB=L1(2)
144 L1=L1+144.145.144
145 J0 L01 L=1.0L
-----
A(12.0)=1.0175*(12.0)+1.0175*(12.0)+1.0175*(12.0)
A(12.0)=1.0175*(12.0)+1.0175*(12.0)+1.0175*(12.0)
IF (CODE(12.0).EQ.2) GO TO 15
IF (CODE(12.0).EQ.3) GO TO 16
IF (CODE(12.0).EQ.4) GO TO 15
A(12.0)=1.0302*(12.0)+1.0302*(12.0)+1.0302*(12.0)
15 A(12.0)=1.0302*(12.0)+1.0302*(12.0)+1.0302*(12.0)
A(12.0)=1.0302*(12.0)+1.0302*(12.0)+1.0302*(12.0)
A(12.0)=(N1(12.0)+.02+.30)*A(12.0)
A(12.0)=(1.000+.004*(12.0)+1.0302*(12.0)+.30)*A(12.0)
C=N(12.0)
GO TO 101
151 A(12.0)=1.0302*(12.0)+1.0302*(12.0)+1.0302*(12.0)
A(12.0)=1.0302*(12.0)+1.0302*(12.0)+1.0302*(12.0)
GO TO 101
161 A(12.0)=1.0302*(12.0)+1.0302*(12.0)+1.0302*(12.0)
101 CONTINUE
145 L=L1(3)
IF (L=0) GOTO 141, 141, 141
161 J0 L02 L=1.0L
-----
A(13.0)=1.0175*(13.0)+1.0175*(13.0)+1.0175*(13.0)
A(13.0)=1.0175*(13.0)+1.0175*(13.0)+1.0175*(13.0)
A(13.0)=1.0175*(13.0)+1.0175*(13.0)+1.0175*(13.0)
IF (CODE(13.0).EQ.2) GO TO 17
IF (CODE(13.0).EQ.3) GO TO 18
IF (CODE(13.0).EQ.4) GO TO 17
A(13.0)=1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
C=N(13.0)+1.50)*N(13.0)
GO TO 171
171 A(13.0)=1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
C=N(13.0)+1.50)*N(13.0)
171 IF (CODE(13.0).EQ.2) GO TO 17
IF (CODE(13.0).EQ.3) GO TO 18
IF (CODE(13.0).EQ.4) GO TO 17
A(13.0)=1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
C=N(13.0)+1.50)*N(13.0)
GO TO 171
18 A(13.0)=A(13.0)+1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
C=N(13.0)+1.50)*N(13.0)
19 IF (CODE(13.0).EQ.2) GO TO 20
IF (CODE(13.0).EQ.3) GO TO 21
IF (CODE(13.0).EQ.4) GO TO 20
GO TO 102
20 A(13.0)=A(13.0)+1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
GO TO 102
21 A(13.0)=A(13.0)+1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
C=2.05
GO TO 102
22 A(13.0)=A(13.0)+1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
GO TO 23
23 A(13.0)=A(13.0)+1.0302*(13.0)+1.0302*(13.0)+1.0302*(13.0)
GO TO 24
24 A(13.0)=(1.0033*(13.0)+1.50)*N(13.0)+A(13.0)

```



ESTI

-133-

COC + 000 FI. VS. -FL 10 001=4 13/10/23. 14

25 $AN(3,L) = (1.0011 * N(3,L) + .005 * U(3,L) + U(3,L) * .0011 * U(3,L) + .025 * U(3,L))$
 $C(3,L) = 1.50$

IF (CODE4(3,L).EQ.2) GO TO 26
 $- (1.0011 * N(3,L) + .005 * U(3,L) + .025 * U(3,L))$

26 $AE(3,L) = .005 * U(3,L) + (1.0011 * N(3,L) + .025 * U(3,L))$

27 $- (1.0011 * N(3,L) + .005 * U(3,L) + .025 * U(3,L) + .0011 * U(3,L) + .0011 * U(3,L))$

$- (1.0011 * N(3,L) + .005 * U(3,L) + .025 * U(3,L))$

IF (CODE3(3,L).EQ.2) GO TO 28

$AJ(3,L) = AJ(3,L) + ((.0005 * U(3,L) + T(3,L) * U(3,L) + .025 * U(3,L)) * N(3,L))$

GO TO 29

28 $AJ(3,L) = AJ(3,L) + ((.0012 * .0005 * U(3,L) + T(3,L) * U(3,L) + .025 * U(3,L)) * N(3,L))$

29 IF (CODE4(3,L).EQ.1) GO TO 3

IF (CODE4(3,L).EQ.2) GO TO 31

IF (CODE4(3,L).EQ.3) GO TO 32

IF (CODE4(3,L).EQ.4) GO TO 33

GO TO 102

30 $AJ(3,L) = AJ(3,L) + ((.0043 * .001 * U(3,L)) * N(3,L) + .025 * U(3,L))$

GO TO 102

31 $AB(3,L) = (2.0 * U(3,L) + 2.00) * N(3,L)$

$AD(3,L) = (2.0 * U(3,L) + 2.00) * N(3,L)$

$AC(3,L) = (2.0 * U(3,L) + 3.00) * N(3,L)$

$AE(3,L) = (1.5 * U(3,L) + 3.00) * N(3,L)$

GO TO 102

32 $AB(3,L) = (4.0 * U(3,L) + 2.00) * N(3,L)$

$AD(3,L) = (2.5 * U(3,L) + 2.00) * N(3,L)$

$AC(3,L) = (5.0 * U(3,L) + 2.00) * N(3,L)$

$AE(3,L) = (3.0 * U(3,L) + 0.00) * N(3,L)$

GO TO 102

33 $AJ(3,L) = AJ(3,L) + 2.00$

102 CONTINUE

191 $LF = L1(5)$

IF (LF - 0) 440, 441, 440

440 GO TO 3 L=1.00

$AN(4,L) = (1.40 * U(4,L) + 4.00) * N(4,L)$

IF (CODE2(4,L).EQ.1) GO TO 341

$AC(4,L) = ((.055 * T(4,L) + .032 * T(4,L) * U(4,L) + .5 * U(4,L)) * N(4,L))$

$AD(4,L) = (1.00 * U(4,L) + 1.00) * N(4,L)$

GO TO 103

341 $AB(4,L) = AN(4,L)$

$AN(4,L) = 0.$

$AD(4,L) = (4.00 * U(4,L) + (T(4,L) * .055 * .02) * N(4,L))$

103 CONTINUE

441 $L1 = L1(5)$

IF (L1 - 0) 442, 443, 442

442 GO TO 4 L=1.00

$AA(5,L) = (1.02 * U(5,L) + .50) * N(5,L)$

$AB(5,L) = (1.07 * U(5,L) + 1.00) * N(5,L)$

$AD(5,L) = (1.04 * U(5,L) + .20) * N(5,L)$

104 CONTINUE

443 $LF = L1(6)$

IF (LF - 0) 444, 445, 444



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494 DO 105 C=1.0F

$$AB(6,L) = (1.5 + .45 * (10.L) * (10.L))$$

$$IF (11.L) - 1.0) 34 134.35$$

 34
$$AU(6,L) = (1.5 + .45 * (10.L) * (10.L))$$

$$GO TO 13$$
35
$$AD(6,L) = (1.5 + .45 * (10.L) * (10.L))$$
36
$$AN(6,L) = (1.5 + .45 * (10.L) * (10.L))$$

IF (CODE2(6,L),20.1) GO TO 37

IF (CODE2(6,L),20.1) GO TO 37

IF (CODE2(6,L),20.1) GO TO 37

GO TO 105

37
$$AN(6,L) = AN(6,L) + .05 * U(6,L) * (10.L)$$

GO TO 41

38
$$AB(6,L) = AB(6,L) + 1.15 * .52 * U(6,L) * (10.L) * (10.L)$$

IF (10.L) - 0.1) 39 34.40

39
$$AU(6,L) = AU(6,L) + 1.15 * (10.L) * (10.L) * .2 * .50 * (10.L)$$

GO TO 41

40
$$AD(6,L) = (1.50 + .50 * U(6,L) * (10.L) * .2) * (10.L)$$

AC(6,L) = (1.50 + .2 * U(6,L) * (10.L) * .2) * (10.L)

41 IF (CODE3(6,L),20.1) GO TO 42

GO TO 43

42
$$AU(6,L) = AU(6,L) - 1.50$$

43 IF (CODE4(6,L),20.1) GO TO 44

GO TO 105

44
$$AA(6,L) = 1.00 * (10.L)$$
$$AB(6,L) = AB(6,L) + 1.02 * U(6,L) * 1.50 * (10.L)$$
$$AU(6,L) = AU(6,L) + 1.00 * U(6,L) * (10.L) * .2 * .2 * (10.L) * .4 * (10.L) * .2$$

C=1.0F

105 CONTINUE

495 LU=L(1)

IF (LU - 1498.447.447)

496 DO 107 C=1.00

$$AH(7,L) = (1.015 * (17.L) * .20) * U(7,L) * .30 * (17.L)$$
$$AN(7,L) = 1.04 * (17.L) * .20 * (17.L)$$
$$AU(7,L) = .30 * (17.L)$$
$$AD(7,L) = 1.50 * U(7,L) * (17.L) * .2 * .50 * (17.L)$$

IF (U(7,L) - 12.1) 45.45.40

45 GO TO 47

46 IF (17.L) - 1.147.447.40

47 GO TO 47

48
$$AU(7,L) = .30 * AU(7,L)$$

49 IF (CODE2(7,L),20.1) GO TO 50

GO TO 100

50
$$AU(7,L) = AU(7,L) * 1.50$$

100 CONTINUE

497 LU=L(2)

IF (LU - 51498.447.447)

498 DO 107 C=1.0

$$AS(8,L) = (1.0 * U(8,L) * .20) * (18.L)$$
$$AB(8,L) = (1.2 * U(8,L) * .20) * (18.L)$$
$$AU(8,L) = .30 * (18.L)$$
$$AD(8,L) = 1.12 * U(8,L) * .20 * (18.L)$$

IF (CODE2(8,L),20.1) GO TO 51

GO TO 107

51
$$AD(8,L) = 1.5 * AU(8,L)$$

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-137- CUC 5000 F1 13/10/23. 14.

```
610 DO BCL C=1.0
  AD(22.0)=1.50*(LL(22.0)+W(22.0))
  AD(22.0)=1.50*(LL(22.0)+W(22.0))
  IF (CODE(22.0).EQ.1) GO TO 74
  GO TO 121
74 AD(22.0)=1.50*AD(22.0)
121 CONTINUE
611 DO 137 J=1.50
  AA1(J)=0.
  AA1(J)=0.
  AC1(J)=0.
  AF1(J)=0.
  AP1(J)=0.
  AU1(J)=0.
  AX1(J)=0.
  AL1(J)=0.
  AA1(J)=0.
  AF1(J)=0.
  AP1(J)=0.
  AU1(J)=0.
  AX1(J)=0.
  AS1(J)=0.
  AT1(J)=0.
137 AU1(J)=0.
  J=1
  DO 702 K=1.5
  IF (L1(K)-0) 703, 702, 703
703 LR=L1(K)
  DO 502 L=1.0
  AA1(J)=AA1(K,L)
  AF1(J)=AF1(K,L)
502 J=J+1
702 CONTINUE
  J=1
  DO 704 N=1.12
  IF (L1(K)-0) 705, 704, 705
705 LR=L1(K)
  DO 600 L=1.0
  DO 600 I=1.0
680 NAME1(I,J)=NAME(K,L,I)
  NA1(J)=NA(K,L)
  AU1(J)=AU(K,L)
  AJ1(J)=AJ(K,L)
  AK1(J)=AK(K,L)
  AL1(J)=AL(K,L)
  AM1(J)=AM(K,L)
  AU1(J)=AU(K,L)
  AS1(J)=AS(K,L)
800 J=J+1
704 CONTINUE
  L2=J
  PRINT 200,NUMBER,ATTEN
```

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COC 600 PTV 45.0-P29 UP1=1 13/10/23. 14.

```

SUM(13)=SUM(13)+A(110)
SUM(14)=SUM(14)+A(110)
SUM(15)=SUM(15)+A(110)
SUM(16)=SUM(16)+A(110)
SUM(17)=SUM(17)+A(110)
140 SUM(18)=SUM(18)+A(110)
PRINT 200,NORDEH,A(110)
200 FORMAT(1,50A,5HURDEH,N0,1A,15,1A,5H10,1,2//)
PRINT 201,(C(10),J=1,4)
201 FOR J=1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392,393,394,395,396,397,398,399,400,401,402,403,404,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,422,423,424,425,426,427,428,429,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,448,449,450,451,452,453,454,455,456,457,458,459,460,461,462,463,464,465,466,467,468,469,470,471,472,473,474,475,476,477,478,479,480,481,482,483,484,485,486,487,488,489,490,491,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,507,508,509,510,511,512,513,514,515,516,517,518,519,520,521,522,523,524,525,526,527,528,529,530,531,532,533,534,535,536,537,538,539,540,541,542,543,544,545,546,547,548,549,550,551,552,553,554,555,556,557,558,559,560,561,562,563,564,565,566,567,568,569,570,571,572,573,574,575,576,577,578,579,580,581,582,583,584,585,586,587,588,589,590,591,592,593,594,595,596,597,598,599,600,601,602,603,604,605,606,607,608,609,610,611,612,613,614,615,616,617,618,619,620,621,622,623,624,625,626,627,628,629,630,631,632,633,634,635,636,637,638,639,640,641,642,643,644,645,646,647,648,649,650,651,652,653,654,655,656,657,658,659,660,661,662,663,664,665,666,667,668,669,670,671,672,673,674,675,676,677,678,679,680,681,682,683,684,685,686,687,688,689,690,691,692,693,694,695,696,697,698,699,700,701,702,703,704,705,706,707,708,709,710,711,712,713,714,715,716,717,718,719,720,721,722,723,724,725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,756,757,758,759,760,761,762,763,764,765,766,767,768,769,770,771,772,773,774,775,776,777,778,779,780,781,782,783,784,785,786,787,788,789,790,791,792,793,794,795,796,797,798,799,800,801,802,803,804,805,806,807,808,809,810,811,812,813,814,815,816,817,818,819,820,821,822,823,824,825,826,827,828,829,830,831,832,833,834,835,836,837,838,839,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,855,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886,887,888,889,890,891,892,893,894,895,896,897,898,899,900,901,902,903,904,905,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,921,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,968,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,984,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,1000,1001,1002,1003,1004,1005,1006,1007,1008,1009,1010,1011,1012,1013,1014,1015,1016,1017,1018,1019,1020,1021,1022,1023,1024,1025,1026,1027,1028,1029,1030,1031,1032,1033,1034,1035,1036,1037,1038,1039,1040,1041,1042,1043,1044,1045,1046,1047,1048,1049,1050,1051,1052,1053,1054,1055,1056,1057,1058,1059,1060,1061,1062,1063,1064,1065,1066,1067,1068,1069,1070,1071,1072,1073,1074,1075,1076,1077,1078,1079,1080,1081,1082,1083,1084,1085,1086,1087,1088,1089,1090,1091,1092,1093,1094,1095,1096,1097,1098,1099,1100,1101,1102,1103,1104,1105,1106,1107,1108,1109,1110,1111,1112,1113,1114,1115,1116,1117,1118,1119,1120,1121,1122,1123,1124,1125,1126,1127,1128,1129,1130,1131,1132,1133,1134,1135,1136,1137,1138,1139,1140,1141,1142,1143,1144,1145,1146,1147,1148,1149,1150,1151,1152,1153,1154,1155,1156,1157,1158,1159,1160,1161,1162,1163,1164,1165,1166,1167,1168,1169,1170,1171,1172,1173,1174,1175,1176,1177,1178,1179,1180,1181,1182,1183,1184,1185,1186,1187,1188,1189,1190,1191,1192,1193,1194,1195,1196,1197,1198,1199,1200,1201,1202,1203,1204,1205,1206,1207,1208,1209,1210,1211,1212,1213,1214,1215,1216,1217,1218,1219,1220,1221,1222,1223,1224,1225,1226,1227,1228,1229,1230,1231,1232,1233,1234,1235,1236,1237,1238,1239,1240,1241,1242,1243,1244,1245,1246,1247,1248,1249,1250,1251,1252,1253,1254,1255,1256,1257,1258,1259,1260,1261,1262,1263,1264,1265,1266,1267,1268,1269,1270,1271,1272,1273,1274,1275,1276,1277,1278,1279,1280,1281,1282,1283,1284,1285,1286,1287,1288,1289,1290,1291,1292,1293,1294,1295,1296,1297,1298,1299,1300,1301,1302,1303,1304,1305,1306,1307,1308,1309,1310,1311,1312,1313,1314,1315,1316,1317,1318,1319,1320,1321,1322,1323,1324,1325,1326,1327,1328,1329,1330,1331,1332,1333,1334,1335,1336,1337,1338,1339,1340,1341,1342,1343,1344,1345,1346,1347,1348,1349,1350,1351,1352,1353,1354,1355,1356,1357,1358,1359,1360,1361,1362,1363,1364,1365,1366,1367,1368,1369,1370,1371,1372,1373,1374,1375,1376,1377,1378,1379,1380,1381,1382,1383,1384,1385,1386,1387,1388,1389,1390,1391,1392,1393,1394,1395,1396,1397,1398,1399,1400,1401,1402,1403,1404,1405,1406,1407,1408,1409,1410,1411,1412,1413,1414,1415,1416,1417,1418,1419,1420,1421,1422,1423,1424,1425,1426,1427,1428,1429,1430,1431,1432,1433,1434,1435,1436,1437,1438,1439,1440,1441,1442,1443,1444,1445,1446,1447,1448,1449,1450,1451,1452,1453,1454,1455,1456,1457,1458,1459,1460,1461,1462,1463,1464,1465,1466,1467,1468,1469,1470,1471,1472,1473,1474,1475,1476,1477,1478,1479,1480,1481,1482,1483,1484,1485,1486,1487,1488,1489,1490,1491,1492,1493,1494,1495,1496,1497,1498,1499,1500,1501,1502,1503,1504,1505,1506,1507,1508,1509,1510,1511,1512,1513,1514,1515,1516,1517,1518,1519,1520,1521,1522,1523,1524,1525,1526,1527,1528,1529,1530,1531,1532,1533,1534,1535,1536,1537,1538,1539,1540,1541,1542,1543,1544,1545,1546,1547,1548,1549,1550,1551,1552,1553,1554,1555,1556,1557,1558,1559,1560,1561,1562,1563,1564,1565,1566,1567,1568,1569,1570,1571,1572,1573,1574,1575,1576,1577,1578,1579,1580,1581,1582,1583,1584,1585,1586,1587,1588,1589,1590,1591,1592,1593,1594,1595,1596,1597,1598,1599,1600,1601,1602,1603,1604,1605,1606,1607,1608,1609,1610,1611,1612,1613,1614,1615,1616,1617,1618,1619,1620,1621,1622,1623,1624,1625,1626,1627,1628,1629,1630,1631,1632,1633,1634,1635,1636,1637,1638,1639,1640,1641,1642,1643,1644,1645,1646,1647,1648,1649,1650,1651,1652,1653,1654,1655,1656,1657,1658,1659,1660,1661,1662,1663,1664,1665,1666,1667,1668,1669,1670,1671,1672,1673,1674,1675,1676,1677,1678,1679,1680,1681,1682,1683,1684,1685,1686,1687,1688,1689,1690,1691,1692,1693,1694,1695,1696,1697,1698,1699,1700,1701,1702,1703,1704,1705,1706,1707,1708,1709,1710,1711,1712,1713,1714,1715,1716,1717,1718,1719,1720,1721,1722,1723,1724,1725,1726,1727,1728,1729,1730,1731,1732,1733,1734,1735,1736,1737,1738,1739,1740,1741,1742,1743,1744,1745,1746,1747,1748,1749,1750,1751,1752,1753,1754,1755,1756,1757,1758,1759,1760,1761,1762,1763,1764,1765,1766,1767,1768,1769,1770,1771,1772,1773,1774,1775,1776,1777,1778,1779,1780,1781,1782,1783,1784,1785,1786,1787,1788,1789,1790,1791,1792,1793,1794,1795,1796,1797,1798,1799,1800,1801,1802,1803,1804,1805,1806,1807,1808,1809,1810,1811,1812,1813,1814,1815,1816,1817,1818,1819,1820,1821,1822,1823,1824,1825,1826,1827,1828,1829,1830,1831,1832,1833,1834,1835,1836,1837,1838,1839,1840,1841,1842,1843,1844,1845,1846,1847,1848,1849,1850,1851,1852,1853,1854,1855,1856,1857,1858,1859,1860,1861,1862,1863,1864,1865,1866,1867,1868,1869,1870,1871,1872,1873,1874,1875,1876,1877,1878,1879,1880,1881,1882,1883,1884,1885,1886,1887,1888,1889,1890,1891,1892,1893,1894,1895,1896,1897,1898,1899,1900,1901,1902,1903,1904,1905,1906,1907,1908,1909,1910,1911,1912,1913,1914,1915,1916,1917,1918,1919,1920,1921,1922,1923,1924,1925,1926,1927,1928,1929,1930,1931,1932,1933,1934,1935,1936,1937,1938,1939,1940,1941,1942,1943,1944,1945,1946,1947,1948,1949,1950,1951,1952,1953,1954,1955,1956,1957,1958,1959,1960,1961,1962,1963,1964,1965,1966,1967,1968,1969,1970,1971,1972,1973,1974,1975,1976,1977,1978,1979,1980,1981,1982,1983,1984,1985,1986,1987,1988,1989,1990,1991,1992,1993,1994,1995,1996,1997,1998,1999,2000,2001,2002,2003,2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,2031,2032,2033,2034,2035,2036,2037,2038,2039,2040,2041,2042,2043,2044,2045,2046,2047,2048,2049,2050,2051,2052,2053,2054,2055,2056,2057,2058,2059,2060,2061,2062,2063,2064,2065,2066,2067,2068,2069,2070,2071,2072,2073,2074,2075,2076,2077,2078,2079,2080,2081,2082,2083,2084,2085,2086,2087,2088,2089,2090,2091,2092,2093,2094,2095,2096,2097,2098,2099,2100,2101,2102,2103,2104,2105,2106,2107,2108,2109,2110,2111,2112,2113,2114,2115,2116,2117,2118,2119,2120,2121,2122,2123,2124,2125,2126,2127,2128,2129,2130,2131,2132,2133,2134,2135,2136,2137,2138,2139,2140,2141,2142,2143,2144,2145,2146,2147,2148,2149,2150,2151,2152,2153,2154,2155,2156,2157,2158,2159,2160,2161,2162,2163,2164,2165,2166,2167,2168,2169,2170,2171,2172,2173,2174,2175,2176,2177,2178,2179,2180,2181,2182,2183,2184,2185,2186,2187,2188,2189,2190,2191,2192,2193,2194,2195,2196,2197,2198,2199,2200,2201,2202,2203,2204,2205,2206,2207,2208,2209,2210,2211,2212,2213,2214,2215,2216,2217,2218,2219,2220,2221,2222,2223,2224,2225,2226,2227,2228,2229,2230,2231,2232,2233,2234,2235,2236,2237,2238,2239,2240,2241,2242,2243,2244,2245,2246,2247,2248,2249,2250,2251,2252,2253,2254,2255,2256,2257,2258,2259,2260,2261,2262,2263,2264,2265,2266,2267,2268,2269,2270,2271,2272,2273,2274,2275,2276,2277,2278,2279,2280,2281,2282,2283,2284,2285,2286,2287,2288,2289,2290,2291,2292,2293,2294,2295,2296,2297,2298,2299,2300,2301,2302,2303,2304,2305,2306,2307,2308,2309,2310,2311,2312,2313,2314,2315,2316,2317,2318,2319,2320,2321,2322,2323,2324,2325,2326,2327,2328,2329,2330,2331,2332,2333,2334,2335,2336,2337,2338,2339,2340,2341,2342,2343,2344,2345,2346,2347,2348,2349,2350,2351,2352,2353,2354,2355,2356,2357,2358,2359,2360,2361,2362,2363,2364,2365,2366,2367,2368,2369,2370,2371,2372,2373,2374,2375,2376,2377,2378,2379,2380,2381,2382,2383,2384,2385,2386,2387,2388,2389,2390,2391,2392,2393,2394,2395,2396,2397,2398,2399,2400,2401,2402,2403,2404,2405,2406,2407,2408,2409,2410,2411,2412,2413,2414,2415,2416,2417,2418,2419,2420,2421,2422,2423,2424,2425,2426,2427,2428,2429,2430,2431,2432,2433,2434,2435,2436,2437,2438,2439,2440,2441,2442,2443,2444,2445,2446,2447,2448,2449,2450,2451,2452,2453,2454,2455,2456,2457,2458,2459,2460,2461,2462,2463,2464,2465,2466,2467,2468,2469,2470,2471,2472,2473,2474,2475,2476,2477,2478,2479,2480,2481,2482,2483,2484,2485,2486,2487,2488,2489,2490,2491,2492,2493,2494,2495,2496,2497,2498,2499,2500,2501,2502,2503,2504,2505,2506,2507,2508,2509,2510,2511,2512,2513,2514,2515,2516,2517,2518,2519,2520,2521,2522,2523,2524,2525,2526,2527,2528,2529,2530,2531,2532,2533,2534,2535,2536,2537,2538,2539,2540,2541,2542,2543,2544,2545,2546,2547,2548,2549,2550,2551,2552,2553,2554,2555,2556,2557,2558,2559,2560,2561,2562,2563,2564,2565,2566,2567,2568,2569,2570,2571,2572,2573,2574,2575,2576,2577,2578,2579,2580,2581,2582,2583,2584,2585,2586,2587,2588,2589,2590,2591,2592,2593,2594,2595,2596,2597,2598,2599,2600,2601,2602,2603,2604,2605,2606,2607,2608,2609,2610,2611,2612,2613,2614,2615,2616,2617,2618,2619,2620,2621,2622,2623,2624,2625,2626,2627,2628,2629,2630
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Appendix II

Computer Program For Multiproject

Scheduling And Man-Power Control

TV 360N-F0-475 3-8

MAINPGM

DATE 07/15/74

TIME

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REAL MON,MSUM
DIMENSION JOR(100,3),S(100),F(100),MON(100,24),Q(100),SUM(100),
CNAME(24,2),MSUM(24),C(100),DAY(24),CS(100),NJOR(6,2),PF(24),NO(6),
C,VAR(24)
INTEGER S,S1,F,Q,QS,Q1,CAY,DEPT(12)
1 READ ACC,S1,L1
400 FORMAT(213)
READ 3, (DEPT(I), I=1,12)
7 FORMAT(12A1)
IF (S1-012,292,2)
2 READ 4, (CNAME(J, I), I=1,2), J=1,12)
READ 4, (CNAME(J, I), I=1,2), J=13,24)
4 FORMAT(24A2)
READ 41C, A1
410 FORMAT(12)
READ 6, (PF(I), J=1,9)
READ 6, (PF(I), J=10,14)
READ 6, (PF(I), J=15,24)
6 FORMAT(91F,1)
READ 7, ((NJOR(I, J), J=1,2), AC(I), I=1,6)
7 FORMAT(6(2A5,15))
N=0
DO 300 I=1,100
READ 1C, (JOR(I, J), J=1,3), S(I), F(I), Q(I)
READ 2C, (JOP(I, J), J=1,3), QS(I)
10 FORMAT(13A3,21A,15)
20 FORMAT(13A3,15)
IF (S(I)-C130,40,30)
30 N=N+1
C(I)=Q(I)-QS(I)
SUM(I)=C
300 CONTINUE
40 READ 70, (DAY(J), J=1,24)
70 FORMAT(24I2)
DO 80 J=1,24
DO 80 I=1,N
MON(I,J)=0
80 MSUM(J)=C
I=1
85 J=L1
SUM(I)=SUM(I)+MON(I,J)
IF (QS(I)-0190,100,90)
90 IF (DAY(J)-F(I)) 115,110,110
110 MCN(I,J)=Q(I)-SUM(I)
GC TC 220
115 IF (DAY(J)-F(I)) 120,120,125
120 MCN(I,J)=(CAY(J)-S1)*Q(I)/(F(I)-S1-5.1)-SUM(I)
SUM(I)=SUM(I)+MCN(I,J)
IF (J-24) 130,135,135
130 J=J+1
GC TC 90
135 GC TC 220
125 MCN(I,J)=C(I)*(F(I)-CAY(J)-2.051-30.1/2.0*(F(I)-5.751)-SUM(I)
SUM(I)=SUM(I)+MON(I,J)

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1 IV 260N-FC-479 3-8

MAINPGM

DATE 07/15/74

TIME

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      IF (J-24) 140, 145, 145
140  J=J+1
      GC TC 90
145  GC TC 220
100  IF (DAY(J)-S(1)) 150, 150, 160
150  PCN(1, J)=0.
      IF (J-24) 151, 152, 152
151  J=J+1
      GC TC 100
152  GC TC 220
160  IF (DAY(J)-F(1)) 170, 165, 165
165  MCN(1, J)=Q(1)-SUM(1)
      GC TC 220
170  IF (DAY(J)-S(1)) 175, 175, 180
175  MCN(1, J)=1*(DAY(J)-S(1))*Q(1)/2.+(F(1)-S(1)-10.)*SUM(1)
      SUM(1)=SUM(1)+MCN(1, J)
      IF (J-24) 185, 190, 190
185  J=J+1
      GC TC 160
190  GC TC 220
180  IF (DAY(J)-F(1)) 195, 195, 200
195  MON(1, J)=Q(1)*(DAY(J)-S(1))/(F(1)-S(1)-10.)*SUM(1)
      SUM(1)=SUM(1)+MON(1, J)
      IF (J-24) 205, 210, 210
205  J=J+1
      GC TC 160
210  GC TC 220
200  MON(1, J)=Q(1)*(F(1)-DAY(J))*Q(1)/2.+(F(1)-S(1)-10.)*SUM(1)
      SUM(1)=SUM(1)+MON(1, J)
      IF (J-24) 215, 220, 220
215  J=J+1
      GC TC 160
220  IF (J-24) 225, 230, 230
225  I=1
      CO TC 85
230  CO 225 I=1, N
      CO 225 J=1, 24
235  MSUM(J)=MSUM(J)+MON(1, J)
      CO 236 I=1, N
      CO 236 J=1, 24
      IF (MCN(1, J)-0.1236, 298, 236)
238  MON(1, J)=10000.0
236  CONTINUE
      CO 285 L=1, 2
      K1=L1
      K2=L1+7
237  PRINT 240, (DEPT(I), I=1, 12)
240  FORMAT(1H1, 20X, 32HLABOUR FORECAST FOR MULTIPROJECTS, 5X, 12A1//)
      PRINT 250, (NAME(I, J), I=1, 21, J=K1, K2)
250  FORMAT(1X, 8HORDER NO, 1X, 1H., 1X, 9HACTUAL HRS, 1X, 1H., 1X, 9HRS COMPL, 1X, 1H., 1X, 11HBACKLOG HRS, 1X, 1H., 1X, 8(2X, 2A317))
      CO 260 I=1, N
260  PRINT 270, (JOB(I, J), J=1, 3), Q(1), CS(1), Q(1), (MON(1, J), J=K1, K2)
270  FORMAT(1X, 3A3, 1X, 1H., 3X, 15, 1X, 1H., 3X, 15, 1X, 1H., 5X, 15, 3X, 1H., 1A.

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TIME

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CR(F7.1,IX)
PRINT 275,('P'IMP(J),J=K1,K2)
275 FORMAT(1741X,5HTOTAL,3X,1H.,1X,8167.1,1X)
SVAR=C.
DO 350 J=L1,24
VAR(J)=PF(J)-MSUM(J)
350 SVAR=SVAR+VAR(J)
SAFH=C.
DO 310 I=1,N1
310 SNEH=SAFH+NO(I)
S1A=SVAR-SNEH
PRINT 276,('P'IMP(J),J=K1,K2)
PRINT 277,SVAR,VAR(J),J=K1,K2)
276 FORMAT(130X,1AHPREVIOUS FORECAST,1X,1H.,1X,8167.1,1X)
277 FORMAT(129X,9HVARIANCE=,1X,F7.1,1X,1H.,1X,8167.1,1X)
PRINT 278
278 FORMAT(1X,17HNEW BOOKINGS PRS)
DO 288 I=1,N1
288 PRINT 289,('P'IMP(J),J=1,21,AC(I)
289 FORMAT(1/1X,2A3,1X,1H.,3X,15)
PRINT 290,SNEH
290 FORMAT(121X,F7.1)
PRINT 291,S1A
291 FORMAT(1X,47HACTUAL COMPLETION WORK-FORECAST COMPLETION WORK=,1X,F
C7.1)
IF(K2-24)280,285,285
280 K1=K1+8
K2=K2+8
IF(K2-24)315,370,370
370 K2=24
375 CC TC 237
285 CONTINUE
GO TO 1
292 STOP
END

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